STUDIES ON PHYSIOMORPHOLOGICAL RESPONSE OF *Mentha arvensis* L. TO NITROGEN, PHOSPHORUS, GIBBERELLIC ACID AND KINETIN APPLICATOIN

ABSTRACT

THESIS

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE OF

Doctor of Philosophy

IN

BOTANY

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DEPARTMENT OF BOTANY
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2003

Abstract of Thesis Entitled

Studies on Physiomorphological Response of *Mentha arvensis* L. to Nitrogen, Phosphorus, Gibberellic Acid and Kinetin Application

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Six pot experiments were conducted at Aligarh (India) during 2000 and 2001 to test the efficacy of soil-applied nitrogen or phosphorus and leaf-applied gibberellic acid or kinetin alone and as well as in combination (nutrient × phytohormones) on *Mentha arvensis* L. so as to select their optimum doses.

Experiment 1 was conducted to study the effect of 5 levels of soil-applied N (0, 30, 60, 90 and 120kg N/ha) applied at 70 days after planting (DAP) on (i) growth (plant height, root length, leaf area, leaf area ratio, specific leaf area, leaf dry weight, specific leaf weight, stem dry weight, aboveground plant dry weight and underground plant fresh and dry weights), and (ii) physiology (on the basis of chlorophyll content, chlorophyll harvest, photosynthetic rate, stomatal conductance, photosynthetic water use efficiency, nutrient (NPK) content and nutrient (NPK) uptake, (iii) yield characteristics such as leaf number, branch number, leaf yield, stem yield, herb yield, oil content and oil yield of *Mentha arvensis* L were recorded at 90, 105, 120, 135 and 150 days after planting (DAP). Application of 90kg N/ha proved best among the doses of nitrogen tested for almost all growth, physiological and yield characteristics. The maximum per cent increase in almost all growth, physiological and yield characteristics studied was observed at 105 DAP. At this stage, an increase of 79, 23 and 46 per cent in leaf area, specific leaf area and herb yield respectively was noted because of application of 90kg N/ha.

Experiment 2 was performed to find out a suitable dose of phosphorus for optimum response of *Mentha arvensis* L. The applied doses of phosphorus at 70 DAP were 0, 10, 20, 30 and 40kg P/ha. The parameters and timings of sampling were those

mentioned in Experiment 1. The dose of 30kg P/ha was best in enhancing the characteristics studied. The maximum per cent increase in almost all growth, physiological and yield characteristics was observed at 105 DAP. At this stage, an increase of 92, 52 and 66 per cent in leaf area, specific leaf area and herb yield respectively caused by 30kg P/ha.

Experiment 3 was conducted to determine the effect of foliar spray of gibberellic acid (GA_3) at 70 DAP on *Mentha arvensis* L. The treatments were 10^{-4}M, 10^{-3}M, 10^{-2}M GA_3 and water spray as control (W_0). The parameters and stages of sampling were the same as in Experiments 1 and 2. Among GA_3 treatments, 10^{-4}M proved best for most growth, physiological and yield characteristics. Maximum per cent increase for most parameters recorded at 105 DAP. An increase in leaf area and herb yield ~~is given by~~ 10^{-4}M GA_3 was 26 and 50 per cent respectively.

Experiment 4 was carried out to assess the effect of foliar spray of kinetin treatments at a concentration of 10^{-6}M, 10^{-5}M and 10^{-4}M. W_0 was taken as control. The spray treatments were given at 70 DAP. The growth, physiological and yield characteristics, and stages of sampling were the same as in pervious experiments.

Among Kn treatments, 10^{-5}M proved best for all the characteristics studied. Like in other experiments, maximum per cent increase for most parameters was noted at 105 DAP. At this stage, an increase of 59, 24 and 66 per cent in leaf area, specific leaf area and herb yield respectively resulted from application of 10^{-5}M Kn.

Experiment 5 was performed to study the interaction effect of soil-applied nitrogen and leaf-applied GA_3 or Kn. The applied rates of nitrogen (selected on the basis of Experiment 1) were 0, 60, 90 and 120kg N/ha. GA_3 treatments (selected on the basis of Experiment 3) were 10^{-5}M and 10^{-4}M and Kn treatments (selected on the basis of Experiment 4) were 10^{-6}M and 10^{-5}M. (W_0) ~~was taken~~ as control. The soil applied-nitrogen and foliar treatments of GA_3 and Kn were given at 70 DAP. The characteristics and stages of sampling were the same as those studied in earlier experiments. Application of 90kg N/ha and 10^{-5} GA_3 alone proved best for almost all characteristics studied. Interaction of ~~90kg N/ha~~ × 10^{-5}M GA_3 proved superior for above ground plant characteristics. However, for underground plant characteristics the interaction N_{90} × 10^{-6}M Kn proved best. In this experiment also, maximum per cent

increase for most parameters was recorded at 105 DAP. An increase in leaf area and herb yield generated by 90kg N/ha × 10^{-5}M GA_3 was 221 and 117 per cent respectively at 105 DAP.

Experiment 6 was conducted to assess the interaction effect of soil-applied P and foliar spray of GA_3 and Kn on performance of *Mentha arvensis* L. The applied rates of P (selected on the basis of Experiment 2) were 0, 20, 30 and 40kg P/ha. GA_3 treatments (selected on the basis of Experiment 3) were 10^{-5}M and 10^{-4}M and Kn treatments (selected on the basis of Experiment 4) were 10^{-6}M and 10^{-5}M. ~~W_0 was taken~~ as control. The soil and foliar treatments were applied at 70 DAP. The characteristics and sampling timings were the same as in earlier experiments. Application of 30kg P/ha and 10^{-5}M GA_3 alone gave best results. Interaction of 30kg P/ha × 10^{-5}M GA_3 prove best for above ground plant characteristics, ~~while~~ P_{30} × 10^{-6}M Kn for underground plant characteristics. Like other experiments, maximum per cent increase for most parameters was noted at 105 DAP. Application of 40kg P/ha × 10^{-5}M GA_3 gave 185 and 100% higher leaf area and herb yield respectively at 105 DAP.

The data provide the following new additions to the literature on the efficacy of mineral nutrition and phytohormone on the performance of *Mentha arvensis* L.

~~The performance of Mentha (*Mentha arvensis* L.) crop was studied for the first time under agro-climates of Aligarh, Western Uttar Pradesh and it was found that:-~~

1. The crop flourishes well, the most appropriate stage for crop harvesting ~~was found~~ at 105 days after planting (DAP).
2. The crop responded well to individual application of soil-applied N at 90kg/ha and P at 30kg/ha.
3. Individual effect of leaf-applied GA_3 and Kn, each at 10^{-5}M proved best for most characters studied.
4. Combined application of soil-applied 90kg N/ha and leaf-applied GA_3 at 10^{-5}M proved more beneficial particularly for aboveground parts than their individual application.

5 The better performance of the crop particularly aboveground morphology was observed when crop was grown with soil-applied P at 40kg/ha supplemented with leaf-applied GA_3 at 10^{-5}M

6 Combination of soil-applied 90kg N/ha and leaf-applied 10^{-6}M Kn proved best for underground parts of the crop. You never describe how or why (

7. The underground morphology of the crop was also more favourably affected by the application of soil-applied 30kg P/ha supplemented with leaf-applied 10^{-6}M Kn You never describe how or why!.

1) You never discuss treatment effects on oil yield, which I would think would also be very important.

2) Your paragraphs give more detail and are thus, better than this list, which is very general.

3) Your abstract needs a summary paragraph elucidating the best treatment for commercial growers for biomass and/or oil quality and yield, that should be tested in the field.

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CERTIFICATE

This is to certify that the thesis entitled ***Studies on Physiomorphological Response of Mentha arvensis* L. *to Nitrogen, Phosphorus, Gibberellic Acid and Kinetin Application****, submitted in partial fulfilment of the requirement for the degree of* ***Doctor of Philosophy*** *in* ***Botany*** *is faithful record of bonafied research work carried out at Aligarh Muslim University, Aligarh by* ***Miss Ratooba Shaheen Hashmi*** *under my guidance and supervision and no part of it has been submitted for any other degree or diploma.*

Samiullah

(Samiullah)

Dedicated

to

My mother

Who has always been a source
of inspiration and encouragement for me

I am sure she is very
proud of you, as she should be.

ACKNOWLEDGEMENT

And My Success In My Task
Can Only Come From Allah.
In Him I Trust
And
Unto Him I Turn

(Al Quran)

I bow in reverence to Allah-Tabarik-Tallah, the great artisan and sustainer, who enshowered his bevolence on me and provided me the patience and strength that made this work possible.

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The most exquisite thing God has created must indeed be the parents. From core of my heart I homage to my darling ***mother****, who has always been a source of inspiration, a lighting flame, a treasury of humanity for her erudition and high sense of responsibility. However, I have developed the spirit of cordiality for humanity, just under charity and patronage of my accredited* ***mother****. This is quite confirmity with human values and moral considerations I solemnly pledge to mitigate the painful sufferings of humanity in general.*

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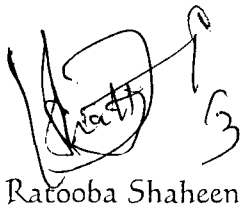
The degnified, genial and chilvalarious personalities, my late father, brother and brother in law who were always ambitious of my reputed career and spent their last days for my education and moulded my behaviour, will remain the asset of my life. May God enshowered endless blessing to their souls.

Lastly but not leastly, God bless the soul of ***Sir Syed Ahmad Khan****, the founder of Aligarh Muslim University, which provided the right platform for my education.*



Ms. Ratooba Shaheen Hashmi

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INTRODUCTION

Chapter 1

INTRODUCTION

Medicinal plants are used as a major source of therapeutic agents for thousand of years. Global interest in medicinal plants, especially in western countries, has increased recently. According to an estimate given by the Export-Import Bank of India in 1997, that the international market of medicinal plants related trade is worth US $ 60 billion per year and growing at the rate of 7% annually. Although China and India represent major sources, India holds apartly 2.5% share (Natesh and Ram, 1999). About 80% of global population and 70% of Indian inhabitants relies on plant-based medicines for primary health care. The demand of plant material for a wide range of human ailments has increased in recent decades because of certain reasons such as rise in population, inadequate supply of drugs in certain parts of the world, unaffordable cost of alternate treatment for common ailments and adverse side effects of several allopathic drugs.

As per report ascribed to the Centre for Research Planning and Action (CERPA), the domestic demand of medicinal plants in 1999-2000 was estimated at Rs. 1,099 Crores which is expected to rise to Rs. 2,000 Crores by the year 2004-2005 (Anonymous, 2001). The Planning Commission of the Government of India has plans to increase the export trade in medicinal plant extracts to Rs. 3,000 Crores by the year 2005 and Rs. 10,000 Crores by the 2010 (Gera *et al.*, 2003).

Raw materials such as leaves, fruits, seeds, roots, bark, rhizomes, stems and even whole plants, used for extraction of chemicals of medicinal importance are exported from the country. Besides these plant parts and whole plants of medicinal importance, the essential oils extracted from some of them are used in organic synthesis of compounds of high economic value. By far about 1,000 genera and 2,500 species have been recognised for their medicinal importance. Among the various plants valued for their essential oil, Japanese mint (*Mentha arvensis* L.) has been recognised as being rich in this commodity. It has also been found to grow faster under Indian conditions. It may be recalled that it was introduced into India in 1954 by the Regional Research Laboratory, Jammu, J & K State (Handa *et al.*, 1954) and

has since been distributed widely in the semi-temperate to tropical agro-climates of the country.

Japanese mint (*Mentha arvensis* L.) is primarily grown for isolation of menthol from its oil, which has wide application in pharmaceutical, the therapeutical, agro-chemical and flavouring industry all over the world. Apart from menthol, the oil contains many valuable terpenes and other minor constituents. Menthol refreshing aroma together with its cooling action, as also its stimulant and antiseptic qualities has led to its wide-spread use for medicinal purpose like inhales, ointments, pain balms, cough syrups, cough lozenges tablets as well as many other health care formulations. Moreover, the oil is directly used as flavouring agent and ingredient in several medicinal preparations (Misra *et al.*, 2000).

Japanese mint (*Mentha arvensis* L.) is commercially grown mostly in Brazil, China, India, Japan, Taiwan and Thailand. According to a survey conducted by the Central Institute of Medicinal and Aromatic Plants (CIMAP), the area under Japanese mint cultivation in India is around 1,34,000 hectares (Kumar *et al.*, 1999). The annual world production estimates for its essential oil is 20,000 tonnes, India has achieved a position of leadership in this field by producing 15,000 tonnes per year (Bahl *et al.*, 2000). However, it has been estimated that Uttar Pradesh (UP) tops the list both with regard to the area under its cultivation and oil production (Misra *et al.*, 2000).

Presently research efforts have been focussed not only on stimulating plant growth for increased herb yield but also to obtain higher oil yield. Some progress has also been made in discerning the physiological modulations of essential oil production which is highly integrated with physiology of whole plant. The assumption that increased production of photosynthetates is an important determinant of oil yield and of its composition (Srivastava and Sharma, 1991). Elucidation of essential oil synthesis pathway indicates that the increase in carbon skeleton provided by photosynthesis during vegetative phase enhances essential oil production. The recent confirmation of involvement of glyceraldehyde-3-phosphate and pyruvate in plastidal essential oil terpenoid biosynthesis has underlined the direct relevance of photosynthesis (Sangwan *et al.*, 2001). With increased production of photosynthetates in mind, plant morphology (size and orientation of leaves and branches) could be

modified so as to achieve better light interception. A few studies undertaken towards the end of the last century have revealed that photosynthetic biomass and oil production respond positively to application of fertilizer nitrogen and phosphorus (Banis *et al.*, 1977; Chandra *et al.*, 1983, Chuhan *et al.*, 1991; Anurag and Singh, 1998; Srivastava *et al.*, 2001; Krishnamoorthy and Madalagri, 2002).

Demonstrations have also shown that mineral nutrient deficiencies substantially impair production of dry matter and its partitioning between the plant organs (Marschner *et al.*, 1996; McDonald *et al.*, 1996) and reduces sink strength (Farrar and Williams, 1991; Paul and Stitt, 1993), there by reducing the photosynthetic potential of source ~~viz.~~ leaves (Farrar and Williams, 1991; Stitt, 1991; Pollock and Farrar, 1996). Nitrogen and phosphorus may also directly affect leaf metabolism via altered activity of photosynthetic enzymes (Stitt, 1991; Quick *et al.*, 1992; Fichtner *et al.*, 1993).

Fertilizer applications generally increase the oil yield by enhancing the amount of biomass per unit area (Sangwam *et al.*, 2001). Moreover, application of nitrogen and phosphorus as fertilizers has been an established practice for increasing the inherent capacity of crops for growth and yield. However, the awakening about soil and water degradation due to indiscriminate application of polluting doses of fertilizers together with their escalating unaffordable prices calls for caution. It therefore appears appropriate to discover and test innovative practices so as to augment the yield of the crop as a result of better utilization of the inputs (fertilizers, including nitrogen and phosphorus). Thus, the crop management should be undertaken in such a way that the available resources are utilized to the maximum possible extent. One such option for achieving this goal is to try and increase the efficacy of the crop for harvesting more solar energy. This would be expected subsequently to increase the amount of photosynthetic metabolites, followed by their translocation and utilization for essential oil biosynthesis. This goal could be achieved either by genetic manipulation or by proper and efficacious modification of cultural practices. The former being a long drawn out time-consuming process, adoption of the latter option may be preferred. In this context, one may visualize that enhanced above

ground crop growth would normally require more soil inputs causing environmental problems.

To offset this undesirable situation, the use of phytohormones for further augmenting the production and expanse of foliage may be undertaken profitably as phytohormones are known to be actively engaged in various physiological activities (Premabatidevi, 1998; Angrish *et al.*, 2001; Elanchezhian, 2001; Pandey *et al.*, 2001; Takei *et al.*, 2002; Khan and Samiullah, 2003). Moreover, phytohormones act as mediators for acclimation of plants to leaf canopy (Pons *et al.*, 2001), stimulate leaf area expansion (Leopold and Kawase, 1964; Brock, 1993) and induce elongation and osmoregulation in internodes (Azuma, 1997). The exogenous application of phytohormones ~~evoked~~ has been demonstrated to evoke the intrinsic genetic potential of crops (Moore, 1989; Taiz and Zeiger, 1998). Most of phytohormones increase dry matter and biomass production (Bhasker *et al.*, 1997; Kewalanad *et al.*, 1998; Gupta and Datta, 2001). Thus the use of phytohormones to increase foliage production in mint grown with soil-applied nitrogen or phosphorus may have dual advantage. First, increased demand of nutrients by enhanced top growth may lead to better uptake and utilization of nitrogen and phosphorus. Secondly, enhanced aboveground biomass production may benefit essential oil yield. With this dual hypothesis in mind, graded solutions of gibberellic acid (GA_3) and kinetin (Kn) were sprayed on mint (*Mentha arvensis* L.) grown with different levels of soil applied nitrogen or phosphorus so as to achieve the goal envisaged there in.

Six experiments were therefore conducted on Japanese mint (*Mentha arvensis* L.) in pots with the following objectives.

1. To study the individual effect of selected doses of nitrogen and phosphorus applied to the soil on growth, and physiological and yield characteristics of the crop.
2. To study the individual effect of foliar sprays of graded gibberellic acid (GA_3) and kinetin (Kn) solutions on growth, and physiological and yield characteristics of the crop.

3. To study the effect of optimum dose of soil-applied nitrogen (N) in combination with subsequent foliar sprays of graded solutions of gibberellic acid (GA_3) or kinetin (Kn) on growth, physiological and yield characteristics.
4. To study the effect of soil-applied phosphorus in combination with subsequent foliar sprays of graded solutions of gibberellic acid (GA_3) or kinetin (Kn) on growth, physiological and yield characteristics.

REVIEW OF LITERATURE

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REVIEW OF LITERATURE

Chapter 2

REVIEW OF LITERATURE

2.1 Introduction

The use of plants as medicines antedates history. Herbal medicine represents probably the first, and certainly the oldest system of human health care. Almost all civilizations and cultures have employed plants in the treatment of human sickness (Natesh and Mohan Ram, 1999).

From a historical perspective, botany as a science had its origin in the use of herbs as medicines. A major aromatic perennial herb, menthol mint (*Mentha arvensis* L.), belonging to family Labiatae, grown in India for the production of essential oil, occupies a predominant position registering huge amount of mint oil which is more than 53% of global production (Kumar *et al.*, 1997). There is a tremendous demand for mentha oil and its derivatives in the international market for its use in different industries. For the last several years, China have had the monopoly in the mentha oil production and international trade and held number one position till 1995 in producing more than 9000 t oil of its own out of the total world production of 17,000 t. The position entirely changed during 1996, when India became the largest producing country of more than 10,600 t oil. Based on the status of production and export of mentha oil and its poroducts, India presently dominates and holds monopoly in the world trade (Misra *et al.*, 2000). Besides India and China, other principal producing countries include Brazil, Japan and Thailand. According to a recent survey conducted by the Central Institute of Medicinal and Aromatic Plants (CIMAP), the area under menthol mint cultivation in India is estimated around 1,34,000 ha with an average annual production of about 12,000 t of menthol mint oil (Kumar *et al.*, 1999).

There are number of uses for different mint oils. The Japanese mint oil, which has considerably higher percentage, is primary source of menthol. Menthol's refreshing aroma and cooling action, alongwith its stimulants and antiseptic qualities, have led to its wide spread uses for medicinal purposes like inhales, ointments, pain balms, cough syrups, cough lozenges and tablets as well as many other formulations (Misra *et al.*, 2000).

Looking at production figures and medicinal uses of mentha, it is highly desirable to increase its productivity and to obtain good quality and quantity of oil, hence, more net return from unit area. Alongwith balanced nutrition, crop is supplied with any other chemical, which could improve the yield and more economic net return. The success in this strive may be additional advantage to pharmaceutical industries and farmers. One such group of chemical is thought to be plant growth regulators. In this chapter, the information regarding the effect of mineral nutrients and plant growth regulators and their interaction on the performance of mentha and allied crops has been reviewed.

2.2 Mineral nutrition

The dogma of mineral nutrition of plants is very old as can be traced back from the period of Aristotle (384 B.C.–322 B.C.), who recognized that nutritive function separated the living from dead and non-living. A major breakthrough occurred in seventeenth century with von-Helmont (1577–1644) emphasized the importance of nutrients for plants. In 1656 Glauber successfully correlated the stimulatory effect of cattle manure on the growth of plants.

The modern concept of plant nutrition was conceived when de Saussure in 1804 established the role of soil in plant growth. He laid the foundation of scientific research on plant nutrition and for the first time emphasized a close relation between the minerals found in soil and the plants that thrived on it. In 1839, Sprengel stressed the importance of nutrient elements absorbed by the plant from the soil. It was mainly credit to Liebig (1803-1873) that scattered information concerning the importance for mineral nutrients for plant growth was compiled and summarized and that the mineral nutrition of plants was established as scientific discipline (Marschner, 1986).

Plants contain small amounts of about more than hundred elements but only seventeen elements were known to be essential (Salisbury and Ross, 1992). Of the essential elements: nitrogen, phosphorus and potassium have been the subject of voluminous field trials by researchers in the world.

2.2.1 Nitrogen

Nitrogen is required for the crop growth in higher concentration than any other element. The productivity of higher plants is to be large extent depends on nitrogen

nutrition (Brown, 1978; Evan and Seeman, 1989; Costa, 2002). Nitrogen is central determinant of leaf photosynthetic capacity (Field and Mooney, 1986; Evan, 1989; Woodward and Smith, 1994) and yield (Sinclair and Dewit, 1976; Greenwood *et al.*, 1980; Frederick and Hesketh, 1994; Sinclair, 1998; Rao *et al.*, 2000). Its availability increases leaf water potential (Radin and Parker, 1979; Radin and Ackerson, 1981; Radin *et al.*, 1982), wall expansion properties of growing tissue (Durand *et al.*, 1994; Fricke *et al.*, 1997), cell division (Roggatz *et al.*, 1999), production rate of cell and cell length (Mac Adam *et al.*, 1989; Gastal and Nelsen, 1994; Fricke *et al.*, 1997) and leaf area (Robson and Deacen, 1978; Gastal and Saugier, 1986; Mac Donald *et al.*, 1986). The N supply showed significant effect on the expansion of individual leaves and on branching (Wilman and Pearse, 1984; Gastal and Lemarie, 1988; Vos and Biemand, 1992; Taylor *et al.*, 1993; Trapani and Hall, 1996; Vos *et al.*, 1996), and the rate of leaf appearance (Cruz and Boval, 2000).

Leaf N status plays an important role in the regulation of photosynthesis (Grindley, 1997), photosynthetic and light harvesting proteins (Evans, 1983; Field and Mooney, 1986) and light use efficiency (Hirose and Werger, 1987; Pons *et al.*, 1989; Muchow and Sinclair, 1994; Gastal and Lemarie, 1997; Drouet, 1998). The soil N status (Gastal and Lemarie, 2002) and its uptake and distribution (Novoa and Loomis, 1981; Sinclair and Shiraiwa, 1993; Gastal and Lemarie, 2002; Kennedy *et al.*, 2002) of the crop have also major impact on crop growth. In addition to that, N plays a critical role in ionic balance (Van Busichen *et al.*, 1988; Wollenweber and Raven, 1993; Graf *et al.*, 1999), in the regulation of the expression of number of genes (Stitt, 1999; Wang *et al.*, 2000) and in hormone metabolism and translocation (Samuelson and Larsson, 1993; Takei *et al.*, 2001; Takei *et al.*, 2002).

2.2.1.1 *Assimilation of nitrogen*

Acquisition and assimilation of nitrogen is second in importance only to photosynthetic carbon assimilation for plant growth and development (Heichel, 1980). The availability of nitrogen in the rhizosphere regulates crop growth and development by augmenting optimum source and sink development during ontogeny. Plants take up nitrogen as much as possible by the roots (Sinclair and Amir, 1992) and the uptake of N into plant roots is an energy requiring process (Oaks and Hirel, 1985) making the

roots a barrier to N uptake. Nitrate and ammonium ions are major sources of inorganic nitrogen taken up by the roots of higher plants from soil solution (Kleinhoffs and Warner, 1990; Lea *et al.* 1990; Solomonson and Barber, 1990). Ammonium ions are assimilated in roots and transported as amino acids and amides to leaves, ~~while~~ nitrate ions are transported to leaves largely as nitrate (Arzonis and Findenegg, 1986).

The uptake of nitrate by roots depends on concentration of nitrate in soil, volume of soil exploited by roots, rooting density and affinity of roots in absorption of nitrate (Engles and Marschner, 1995; Jeuffory *et al.*, 2002). The assimilation of nitrate by plant requires the uptake of nitrate, reduction of nitrate, the conversion of nitrate to ammonia, and incorporation of ammonia to organic compounds (Migge and Becker, 1996; Sivasankar and Oaks, 1996). Since ammonium is toxic, it is rapidly assimilated into non-toxic metabolites (Lea *et al.*, 1990). The type and concentration of nitrogen in growth media exert a considerable influence on the growth and mineral composition of the crop plants (Kurvits and Kirkby, 1980; Gashaw and Mugwira, 1981). Ammonium on entering the roots of plants ~~are~~ immediately assimilated by the GS-GOGAT system to form glutamine and glutamate (Amancio and Santosh, 1992). The metabolism of nitrate occurs in leaves and roots depending on the species of plant (Lea and Morot-Gaurdy, 2001).

2.2.1.2 Consequences of nitrogen deficiency

Visual diagnosis of nutrient deficiency provides a valuable means of assessing the nutritional condition of crop (Cox and Robson, 1980). The deficiency of essential minerals result in a significant changes in development of various organs and the plant as whole (Sundqvist *et al.*, 1980; Mishra *et al.*, 1985; Dodd, 2001). The deficiency of N causes adverse effects on cell wall properties and activity of enzymes, such as xyloglucan endotransglocoxylase (Palmer and Davies, 1996), and therefore a severe decrease in leaf expansion (Volenec and Nelson, 1984; Palmer *et al.*, 1996). Nitrogen deficits alters source-sink relations, reduces sink activities in shoots resulting in more competitive sinks for photoassimilates into roots than younger leaves and shoot meristems (Aloni *et al.*, 1991). The deficits also stimulates translocation of carbohydrates from source (leaves) to roots (Rufty *et al.*, 1988) and

thus reduces the shoot/root dry weight ratio of the plant (Cakmak *et al.*, 1994a; Peuke *et al.*, 1994; Marschner, 1995; Marschner *et al.*, 1996). Nitrogen stress results in inhibition of shoot expansion (Mac Donald, 1996; Balakrishnan, 1999), decreases cell length in leaf epidermal cells (Mac Donald *et al.*, 1996) decrease in leaf area duration and leaf area index (Lawlor, 1995), relative growth rate (Walker, 2001), leaf area ratio (Boogard *et al.*, 1995) and crop production (Ter Steege *et al.*, 2001) and shortening of vegetative phase (Koch *et al.*, 1988).

The N deficiency also adversely affects the physiological activities of the plant. The limited N supply results the collapse of chloroplast (Thomson and Weier, 1962; Laza *et al.*, 1993; Kutik *et al.*, 1995) and therefore affects on chloroplast development. N deprived plants are pale and yellow in colour, as total chlorophyll reduces in low nitrogen supply (Longstreth and Nobel, 1980; Balakrishnan, 1999). On a decrease in nitrogen supply, the rate of photosynthesis per unit leaf area (Van der Wref *et al.*, 1993), carboxylation capacity (Evans, 1986; Makino *et al.*, 1988; Lawlor *et al.*, 1989) and water use efficiency (Uhart and Andrede, 1995) decreased significantly. Low N decreased the soluble protein content and rate of protein synthesis per leaf, whereas increase in structural to non-structural proteins (Lawlor, 2002).

2.2.2 Phosphorus

Phosphorus is a major mineral nutrient required by plants, but is one of the relatively immobile, inaccessible and unavailable nutrient present in soils (Marschner, 1995; Holford, 1997). Unlike nitrate and sulphate, phosphate is not reduced in plants but remains in its highest oxidised form. After uptake at physiological pH mainly as $H_2PO_4^-$ either it remains as inorganic phosphate or it is esterified through a hydroxyl group to carbon-chain (C–O–P) as a simple phosphate ester (e.g. sugar phosphate) or attached to another phosphate by energy rich pyrophosphate (P) ~ (P) bond (e.g. in ATP). The rates of exchange between inorganic phosphate and organic phosphate in ester and pyrophosphate bond are very high (Marschner, 1986).

Phosphorus is extremely reactive and is only available for plant uptake at a narrow range of neutral soil pH values. In acid soils, phosphorus forms low solubility molecules with aluminium and iron (Bar-Yosef, 1991; Gerke, 1992), whereas in

alkaline soil, it combines efficiently with calcium and magnesium to form sparingly soluble phosphate compounds (Dinkelaker *et al.*, 1989; Bolan *et al.*, 1997). The P supply regulates root development (Bates and Lynch, 1996; Narang *et al.*, 2000; Williamson *et al.*, 2001) and strongly enhances shoot biomass accumulation and leaf area (Rubio *et al.*, 2003) and yield (Barry and Miller, 1989; Rao and Shaktawat, 2001).

Leaf phosphate status plays an important role in the activation of Calvin cycle enzymes (Leegood *et al.*, 1985; Brooks *et al.*, 1988; Rao and Terry, 1989) and in photosynthesis (Flugge, 1987; Paul and Foyer, 2001). Phosphorus (P) is an essential nutrient for plant growth and development, reproduction that forms part of key molecules such as nucleic acids, phospholipids, ATP and other biologically active compounds (Taiz and Zeiger, 1998; Bucio *et al.*, 2000).

2.2.2.1 Mobilization of phosphorus

About 80% of P in soils is found in organic form (Jackson and Hagen, 1960; Richardson, 1994), the remainder is found in organic fraction containing 170 mineral forms (Holford, 1997). The organic compounds allowing the phosphate to be less adsorbed to the soil particles (Bolan *et al.*, 1997) and maximizing uptake of P by the root (Lynch, 1995; Otani *et al.*, 1996). Phosphate taken up by basal root segments is translocated to root tips as well as the upper parts of plant (Clarkson *et al.*, 1968; Mimura *et al.*, 1996; Jeschke *et al.*, 1997).

In P-sufficient plants there is retranslocation of *Pi* in the phloem from older leaves to growing shoots and from shoots to roots (Bouma, 1967; Jeschke *et al.*, 1997). In the xylem P is transported solely as *Pi* (Schachtman *et al.*, 1998), while substantial concentrations of *Pi* are present in the phloem (Hall and Baker, 1972) indicating the role of *Pi* in the phloem transport. In P-deficient plants, root clusters are formed and exude higher amounts of organic acids (upto 23% of net photosynthesis), which acidify the soil and chelate ions in the root resulting in the mobilization of P and some micronutrients (Marschner, 1995). Microrrhizae are also important for P acquisition in plants, since fungal hyphae greatly increase the volume of soil that plant's roots explore (Smith and Read, 1997). Phosphate absorbed by plant cells is rapidly involved in metabolic process. Jackson and Hagen (1960) reported that after a period

of only 10 minutes, following uptake, 80% of the phosphate was incorporated into organic compounds. The organic phosphate formed in this short time consisted of mainly of hexose phosphates and uridinediphosphate.

Under normal physiological conditions, the transport of *Pi* across the plasma membrane from soil to the plants required ~~amount of~~ energy, because of relatively high concentration of *Pi* in the cytoplasm and negative membrane potential of the cells. The stability of cytoplasmic *Pi* concentration is essential for many enzyme reactions and this stability can be achieved by membrane transport and exchange between various intracellular pools of P (Schachtman *et al.*, 1998). The distribution of P into the pools, i.e. physical compartments such as cytoplasm, vacuole, apoplast and nucleus, and into metabolic pools ~~have~~ been studied (Bieleski, 1973; Bieleski and Ferguson, 1983; Lee *et al.*, 1990; Lee and Ratcliffe, 1993; Ratcliffe, 1994; Mimura, 1995; Macklon *et al.*, 1996). To transport *Pi* across cellular membranes involves several different transporters and is in some way regulated by external supply of *Pi* (Furihata *et al.*, 1992). Studies at molecular level have ~~been~~ shown ~~that~~ genes encoding plant phosphate transporters (Delhazie and Randall., 1995; Muchal *et al.*, 1996; Smith *et al.*, 1997; Leggewie *et al.*, 1997; Liu *et al.*, 1998a, 1998b; Bucio *et al.*, 2000) that interact and regulate phosphate-transport mechanisms.

2.2.2.2 Consequences of phosphorus deficiency

Inadequate supply of nutrients causes metabolic disorders (Terry and Ulrich, 1973; Rao and Terry, 1989; Taiz and Zeiger, 1998; Rengel, 2002). The deficiency of P limits the *Pi* concentration in chloroplast and ATP synthesis (Jacob and Lawlor, 1993), regeneration of RUBP and activity of RUBP carboxylase (Brooks, 1986; Freeden *et al.*, 1990), photosynthesis (Tombesi *et al.*, 1969; Brooks *et al.*, 1988; Rao and Terry, 1989; Plesnicar, 1994) and respiration (Terry and Ulrich, 1973; Rao and Terry, 1989). In addition, stomatal conductance (Radin, 1984; Radin and Eidenbock, 1986) and water potential of leaves also decreased under the deficiency of this nutrient (Radin and Eidenbock, 1984). In leaves, the deficiency of P causes substantial increase in allocation of photosynthates to starch and sucrose, ~~while~~ but marked decrease in sugar phosphates (Rao and Terry, 1995).

The appearance and morphology of plant is also affected under P-starved conditions. The plants grown under P deficiency are characterized by smaller, darker-green leaves, shorter petioles, usually small and slender stems, and smaller storage and longer fibrous roots (Devlin and Witham, 1986; Salisburry and Ross, 1992; Taiz and Zieger, 1998). In response to P-limited conditions, some plants undergo developmental adaptations to scavenge limited phosphate from the environment including changes in root architecture, induction of genes encoding high affinity transporters, rhizosphere acidification and exudation of organic acids (Zhang *et al.*, 1997; Schatchman *et al.*, 1998; Raghothama, 1999; Bucio *et al.*, 2000).

Low P availability involves postembryonic developmental changes in the root system (Dinkelaker *et al.*, 1995; Bates and Lynch, 1996; Borch *et al.*, 1999), and restricts the root hair elongation (Schmidt and Schikora, 2001). In P-deficient plants, decrease in root hydraulic conductance causes inhibition of leaf cell expansion (Radin and Eidenbock, 1984). Under P deficiency, a considerably large portion of photosynthates is partitioned to roots than shoots (Engles and Marschner, 1995), leading to reduced shoot/root dry weight ratio (Bouma, 1983; Moorby and Besford, 1983; Rao and Terry, 1989; Rubio *et al.*, 2003).

2.2.3 Potassium

Unlike nitrogen and phosphorus, potassium (K^+) is not a constituent of any metabolic compound (Evans and Sorger, 1966). Potassium plays a key role in turgor regulated movement not only of individual cells, but also of plant organs (Scatter *et al.*, 1974; Kiyosawa, 1979). The circadian movements of leaves are controlled by K^+-mediated turgor changes in specialized tissue (Marschner, 1986).

Potassium plays a fundamental role in the establishment of proton gradient across the thylakoid membrance (Tester and Blatt, 1989) and maintenance of high pH of chloroplast stroma (Fang *et al.*, 1995).

Potassium also required for stomatal conductance, and thus, for efficient CO_2 diffusion into leaves (Humble and Raschke, 1971). The accumulation of potassium in guard cells provides the necessary amount of solute developing for water potential gradient required for water movement into guard cells for stomatal opening ~~necessary~~

for photosynthesis (Jensen and Tophoj, 1985; Tanguilig *et al.*, 1987 and Thakral *et al.*, 1997).

The potassium requirement for optimal plant growth is approximately 2-5% on the dry weight basis of plant. There are more than 50 enzymes which either completely depend on or stimulated by K^+ (Suelter, 1970). Potassium is involved in several steps of translocation process, including binding of tRNA to ribosomes (Evans and Wildes, 1971; Wyn Jones *et al.*, 1979; Nitsos and Evans, 1969) oxidative phosphorylation, glycolysis and adenine synthesis (Evans and Sorger, 1966). Translocation of organic solutes totally depends on potassium ions, which are moved across the sieve plate actively (Salisbury and Ross, 1992). It also involves in various physiological and biological processes (Mengel and Kirkby, 1996; Rengel, 2002).

2.2.3.2 Consequences of potassium deficiency

When potassium is deficient, growth is retarded and potassium (K^+) is retranslocated from mature leaves and stems. When its deficiency is severe the leaves and stems became chlorotic and necrotic (Bussler, 1964) and lignification of vascular bundles is impaired (Pissarek, 1973). During potassium deficiency, the changes in enzymes activity and organic compounds take place are in part responsible for the higher susceptibility of plants to fungal attack. They also affect the nutritional and processing quality of harvested products (Marschner, 1986), and potassium deficient plants have lower tolerance to drought.

In potassium deficient plants reduced internodes of stems, stunted growth of shoot with numerous tillers, ~~but~~ little or no flowering, colour ~~of leaf~~ may be dull blue-green, chlorosis occurs in intervienal region, in older leaves browning of tips, margin scorching or development of brown spots near margins, ~~occur~~. Enhanced respiration rate ~~are~~ common feature of potassium deficiency (Bottrill *et al.*, 1970).

2.3 Response of crops to mineral nutrients

Several investigations have noted beneficial effects ~~of~~ nitrogen and phosphorus in enhancing the yield characteristics, quality and percentage of active constituents, but reports about potassium are meargre. In the following pages, the available literature on the influence of nitrogen and phosphorus on selected medicinal

plants particularly under Indian conditions for the last two decades has been reviewed briefly.

In an investigation Bhardwaj *et al.* (1980) reported that peppermint (*Mentha piperita* L.) responded to high levels of N ~~as much as~~ 120 and 160 kg/ha. Sharma and Singh (1980) reported an economic dose of nitrogen at 199.1 kg/ha and 96.6 kg/ha for Japanese mint (*Mentha arvensis* L.).

Singh *et al.* (1981) noted that an application of 150 kg N/ha increased menthol and methyl acetate content, whereas menthone content increased upto 250 kg N/ha in *Mentha arvensis* and *Mentha piperita*. ~~However~~, linalool content increased, but linyle acetate decreased in bergamot mint (*Mentha citrata*) with the application of 100 kg N/ha. ~~Moreover,~~ Carrone content in *Mentha spicata* increased with increased application of nitrogen.

Singh *et al.* (1983) studied response of bergamot mint (*Mentha citrate*) to graded dozes of nitrogen (0, 50, 100, 150 and 200 kg N/ha) and phosphorus (0, 60 and 120 kg P_2O_5/ha). ~~It was~~ found that a combination of 100 kg N and 60 kg P_2O_5/ha produced maximum herb and oil yields, whereas quality ~~of oil~~ was not altered by different treatments. Rao *et al.* (1983), while studying the individual effects of nitrogen, phosphorus and potassium on same crop, noted that 50 and 100 kg N/ha and 60 kg P_2O_5/ha increased the herbage and essential oil yields; however, K application had no effect on yield. Oil content was not influenced by NPK fertilization.

~~Astadzov (1984) in~~ Summer snowflake (*Lecojum aestivum* L.) ~~application of~~ 100 kg each of N, P_2O_5 and K_2O showed highest herbage yield ~~but had~~ no effect on herbage galatamine content. Kozlowski and Maszner (1984), while studying ~~on~~ sage (*Salvia officinalis*), found that P_2O_5 at 20 upto 80 kg/ha increased plant tannin accumulation, ~~while~~ all P_2O_5 rates except 100 kg/ha depressed essential oil synthesis. In a trial with peppermint (*Mentha piperito*), N at 160 kg/ha produced 9.8-18.4% more oil than ~~that~~ at 80 kg N/ha (Yadav *et al.*, 1985).

Hedge (1986) noted a positive response of perwinkle (*Catharanthus roseus* L. G. Don) to N application. The optimum rates for root and leaf yield were found 110 and 80 kg N/ha respectively. Moreover, a split application in 3 equal doses (at planting, 60 and 120 days later) produced the highest root, leaf and stem yields.

In a study on genotypes of Japanese mint (*Mentha arvensis* L.), it was found that N application upto 150 kg/ha significantly increased plant height, herb and oil yields but leaf stem ratio and oil concentration did not vary appreciably (Kothar *et al.*, 1987). In line with the same crop Singh (1987) observed the effect of ten levels of nitrate doses on its growth and essential oil content. The highest dry weight (10.7 gm) and maximum essential (9.2 ml/100 gm) were found with 16.0 meq/l of nitrate nitrogen.

Van and Gelder (1988) conducted a trial to observe the influence of increasing levels of N application (112–392 kg/ha) on oil production and quality in peppermint (*Mentha piperita* L.). It was observed that decreased menthol and increased menthone contents of oil were associated with increased levels of N. Bhardwaj and Kaushal (1989) reported that 150 kg N/ha should be supplied to obtain highest essential oil and free menthol contents and best physical properties of oil of the same crop.

Ramesh *et al.* (1989), while studying on isubgol (*Plantago ovata* Forsk.), observed that there was little response of the crop in terms of vegetative growth and yield attributes to applied fertilizer rates of NPK. Application of N, P and K at 75, 25 and 30 kg/ha respectively, gave the highest number of spikes and seed yield/plant.

Singh *et al.* (1989) found that N application upto 100 kg/ha significantly increased ~~significantly~~ plant height, leaf stem ratio, leaf area index, herbage and oil yields of mint species, viz. Japanese mint (*Mentha arvensis* L.), peppermint (*Mentha piperita* L.), spearmint (*Mentha spicata* L.) and for bergomot mint (*Mentha citrata* L.) N application upto 150 kg/ha improved these parameters. However, oil content of all species decreased with increasing rates of N. Bhardwaj and Kaushal (1990) observed that N upto 150 kg/ha increased the biomass and oil yields in peppermint cultivars (*Mentha piperita* L.).

Chuhan *et al.* (1991) observed the effect of P (0, 30, 60 and 90 kg/ha) on Japanese mint (*Mentha arvensis* L.). They found that P at 60 kg/ha increased significantly dry matter and essential oil yield over control. Cho and Kim (1991) reported that fertilizer application of 120 kg N, 80 kg P_2O_5 and 80 kg K_2O/ha increased plant height, shoot fresh weight, root length, number of root branches, root

fresh weight and growth of stem nodes. Singh *et al.* (1991) performed an experiment on spearmint (*Mentha spicata* L.). They found that plant height, number of leaves/plant, plant N concentration and essential yields were maximum at 120 kg N/ha.

Farooqi *et al.* (1991) conducted an experiment on davana (*Artemisia pallens* Wall.). They found that treatment with 240 kg N/ha produced maximum plant height, number of branches/plant, plant spread, number of flower heads/plant, fresh weight of herbage/plant, fresh weight of whole plant and computed fresh and oil yield/ha. Application of phosphorus alone failed to influence the growth, yield and oil content. Combined application of nitrogen (240 kg/ha) and phosphorus (80 kg/ha) proved best for most parameters.

Munsi (1992) studied the effect of N (0, 60, 80 or 100 kg/ha) and P (0, 20, 40 or 60 kg/ha) on the yield and essential oil content of Japanese mint (*Mentha arvensis* L.). It was found that dry matter and fresh herb yield were increased more with N than with P. However, interaction of 100 kg N/ha and 60 kg P/ha gave highest yields of fresh herb and essential oil, but the composition of essential oil was not affected by the treatments

Singh *et al.* (1992) conducted a field trial on mint species. The crop was treated with graded levels of N upto 150 kg/ha. It has been reported that 150 kg N/ha increased plant height, leaf stem ratio, leaf area index, dry matter accumulation and oil content significantly, but further addition of nitrogen decreased the oil content.

Courte *et al.* (1993) found that application of N upto 180 kg/ha increased oil yield in peppermint (*Mentha piperita* L.) but the chemical constituents of essential oil were not influenced by N fertilization.

Kothari *et al.* (1993) reported that the economic optimum levels of N for menthol production were 124, 167, 214 and 218 kg/ha in MA2, MAP1, MAS1 and MAS2 genotypes of Japanese mint (*Mentha arvensis* L.) respectively.

Piccaglia *et al.* (1993) applied N at 0, 100 or 200 kg/ha to peppermint (*Mentha piperita* L.). It has been reported that increasing levels of N, increased the biomass and yield of the crop but percentage of leaves in biomass decreased. Saxena *et al.* (1993), working on Japanese mint (*Mentha arvensis* L.) reported that at 150 kg N/ha -

compared with 100 kg N/ha significantly increased the green herb and oil yield. Kothari and Singh (1995) observed the effect of N application on spearmint (*Mentha gracils* Sole). The plant height and leaf area index increased with the application of N but leaf stem ratio and oil concentration decreased. Saxena and Singh (1995) reported that for higher dry matter and essential oil yields, the economic optimum rate of N was 215 kg/ha for Japanense mint (*Mentha arvensis* L.).

Gascho *et al.* (1995) working on pearl millet (*Pinnisetum glaucum* (R) Br.). They reported that the yield of crop increased linearly with N fertilization upto 90 kg/ha. Kannan and Paliwal (1995), working on cassia (*Cassia siamea*), reported that application of N fertilizer had positive effect on growth but application of P or K separately or in combination did not show any significant effect. However, both fertilizers (P or K) in combination with N showed a positive effect.

Michell and Farris (1996), conducting a trial on peppermint (*Mentha piperita*), found that optimum dry matter yield occurred at N rates of 245 and 188 lb/acre and optimum oil yield at N rates of 245 and 252 lb/acre for first and second year, respectively. Saxena and Singh (1996) reported that the agronomic efficiency in terms of oil production for Japanese mint (*Mentha arvensis* L.) was ~~noted as~~ 0.28 kg oil/kg as a result of application of N at 100 kg/ha. Nitrogen at 150 kg/ha increased oil yield by 40.4% and N uptake by 48.5% over the control.

Chalapathi *et al.* (1997) in a field trial on stevia (*Stevia rebaudiana* Bertoric) observed the highest NPK uptake with the application of N, P and K at 60, 30 and 45 kg/ha respectively. Muniramaappa *et al.* (1997) working on Kalmegh (*Andrographis peniculata*) reported that application of N and P at 100 and 75 kg/ha respectively, produced tallest plants, maximum plant spread, number of branches, leaf area, fresh and dry weight per plant and herbage yield per hectare.

Rehman *et al.* (1997) conducted a pot experiment on peppermint (*Mentha piperita* L.). They found that the foliar spray of urea increased number and weight of leaves, number of branches, leaf area, total weight of leaves, length of branches and oil content of leaves.

Ramu and Farooqi (1997) carried out an experiment on rosette (*Hibicus sabdariffa* L. var. Sabdariffa). It was reported that an application of nitrogen at 250

kg/ha enhanced most of the growth and yield parameters and nutrient uptake significantly. However, the maximum seed yield was obtained with 200 kg N/ha. Rastogi *et al.* (1997) studied the effect of N on clary sage (*Saliva Sclarea* L.). N was applied at various levels, viz. 30, 60, 90 and 120 kg/ha. It was found that 90 kg N/ha produced maximum shoot yield (60.52 q/ha) and essential oil yield (38.77 l/ha). The effect of 90 kg N/ha was significantly higher over other levels of nitrogen. Rao *et al.* (1997) conducted a field experiment on davana (*Artemisia pallens* Wall. exD.C.). The crop was treated with nitrogen at 0, 80 or 160 kg/ha. Application of 90 kg N/ha resulted in enhancement of biomass production, essential oil yield and NPK uptake.

Shahidullah *et al.* (1997) observed the highest percentage of oil in spearmint (*Mentha spicata* L.) with an application of 200 kg N/ha. However, plant height, number of branches per plant and herbage yield increased progressively with increase in N rate upto 175 kg/ha.

Shanthaveerabhadriah *et al.* (1997) observed in a field trial a significant response of cardamom (*Elettaria cardamomum* Maton) to N, P, and K at 100, 50 and 100 kg/ha respectively.

Menghini *et al.* (1998) noted the effects of application of urea on the leaves of bacha (*Acorus calamus* L.). It was observed that application of urea significantly increased the photosynthetic rate vs. incident light (Photosynthetic Photon Flux Density), chlorophyll and carotenoid contents.

Pintro *et al.* (1998) observed that the addition of N increased plant height, number of leaves, leaf area and shoot dry weight of erva-mate (*Ilex paraguariensis* st. Hill). However, P and K did not affect these parameters.

Rao *et al.* (1998) in a field experiment noted a positive response of lemongrass (*Cymbopogon flexuosus*) to nitrogen at 100 kg/ha under irrigation and 75 to 80 kg/ha under rainfed condition. Essential oil concentration and quality were not affected by N application. Moreover, crop did not respond to the application of P and K.

Shujun *et al.* (1998) performed an experiment on lour (*Leonurus Artemisia* S.Y.HU.). They found that application of P influenced fresh plant weight, leaf growth rate and tiller number most positively followed by N and K fertilizer. However,

chlorophyll accumulation was maximum with N fertilizers. Solanki *et al.* (1998) found that application of 90 kg N/ha increased plant height and leaf area index of opium poppy (*Papaver somniferum* L.). Subramanian and Kumar (1998) studied the effect of N, P and K on quality of coriander (*Coriandrum sativum*). It was observed that essential oil and oleoresin contents were higher with 30 kg N + 60 kg P + 20 kg K/ha. Wasnikar *et al.* (1998), performing an experiment on betel (*Piper betle*), showed that application of P_2O_5 at 100 kg/ha gave maximum height, number of leaves/vine and fresh weight of 1000 leaves. With regard to keeping quality, all P_2O_5 treatments except 25 kg/ha improved it.

Ali *et al.* (1999) conducting a field trial on peppermint (*Mentha piperita*), ~~and~~ found that 300 kg N/ha and 100 kg P_2O_5/ha were best doses for dry matter and oil yield. Chadha *et al.* (1999) reported that for African marigold (*Tagetes erecta* L.), plants had the highest number of leaves and branches per plant and maximum plant height with 60 kg N/ha ~~while~~ in whereas plants treated with 75 kg P_2O_5/ha had thickest stem and maximum plant spread. Dayanand *et al.* (1999) conducted an experiment on fenugreek (*Trigonella foenum-graecum* L. cv. Rmt–1). They observed that an application of P upto 40 kg/ha enhanced total N uptake significantly.

Lakshmipathaiah *et al.* (1999) made a study on babchi (*Psoralea corylifolia* L.). It was observed that 100 kg N/ha gave the highest values for plant height (123.6 cm), plant spread (458.8 dm^2), number of branches (22.4), number of leaves (273.8), leaf area (1016.8 cm^2) and seed yield (13.4 q/ha).

Mann and Vyas (1999) conducted a field experiment on isubgol (*Plantago ovata* Forsk.). The crop was supplied with four N levels, viz. 0, 15, 30 and 45 kg/ha. It was found that plant height, leaves per plant and dry matter accumulation increased up to 45 kg N/ha. The N, P and K uptake was also enhanced by the highest level of N. Ram *et al.* (1999) performed a pot trial on chamomile (*Chamomilla recutita*). They noted that growth parameters such as plant height, plant spread, number of branches, dry weight of shoots and flower yield increased up to 60 kg N/ha significantly. The highest flower yield was registered with the combined application of 120 kg N + 50 kg P_2O_5 + 50 kg K_2O/ha.

Chauhan *et al.* (2000) studied the performance of different menthol mint (*Mentha arvensis* L.) genotypes to N application. The genotypes Kalka and Gomti responded significantly in respect of herb and oil yield up to 200 kg N/ha, however Himalaya and Kosi, upto 150 kg N/ha. Esendal *et al.* (2000) found that application of N at 150 kg/ha produced highest fresh and herb yield of datura (*Datura stramonium* L.).

Masarovicova *et al.* (2000) while studying the effect of high nitrogen [2.0 mM KNO_3 and 1.5 mM $Ca(NO_3)_2$] and low nitrogen [198.8 µM KNO_3 and 150.8 µM $Ca(NO_3)_2$] supply on species of karwinskia (*Karwinskia parvifolia* and *Karwinskia humboldtiana*). They reported that both species grew faster at high nitrogen supply. Photosynthesis, leaf respiration, root respiration, quantum yield, concentration of chlorophylls (a, b, a+b), specific leaf area and leaf mass ratio were higher in plants grown at high nitrogen supply.

Ojha *et al.* (2000), working on the field grown spearmint (*Mentha spicata*), reported that application of 120 kg N/ha proved best with regard to the yield of crop.

Tiwari *et al.* (2000) reported that application of N at the rate of 100 kg/ha increased the growth and yield of bacha (*Acorus calamus*), including the fresh and dry weight of rhizomes.

Kattimani *et al.* (2001) found that increasing rates of nitrogen (75 to 225 kg/ha) significantly enhanced linearly the biomass and essential oil yields and nitrogen, phosphorus and potassium uptake of Japanese mint (*Mentha arvensis* L.). The crop responded to phosphorus levels upto 40 kg/ha. Combined application of 225 kg N/ha and 40 kg P_2O_5/ha resulted in highest biomass and essential oil yields, and nutrient uptake.

Rai *et al.* (2002) conducting a field trial applied nitrogen at 0, 30, 60 and 90 kg/ha and phosphorus at 0, 25 and 50 kg P/ha to fennel (*Foeniculum vulgare* L.). It was reported that increasing levels of N or P increased linearly plant height, number of branches/plant, number of tillers/plant, length of internode and plant spread Combined application of 90 kg N/ha and 50 kg P/ha proved best for most parameters, including seed yield.

2.4 Phytohormones

Phytohormones or plant hormones are organic compounds synthesised in one part of plant and translocated to another part, where in very low concentrations they cause biochemical, physiological and/or morphological responses (Salisbury and Ross, 1992). Since the sites of synthesis and sites of action are separate, ~~thus~~ transport either from cell to cell or from organ to organ is necessary. The translocation of phytohormones takes place in both phloem (Weiler and Ziegler, 1981) and xylem. The prevailing direction of transport depends on type of phytohormone and developmental stage of the plant (Marschner, 1986).

Phytohormones are extremely important agents in the integration of developmental activities. The synthesis and action of phytohormones are affected by environmental factors such as temperature, daylength and nutrient supply, which exert inductive effects by ~~evoking~~ influencing phytohormone balance within the plant. Generally mechanism of action of phytohormones is poorly understood.

Each phytohormne has a broad action spectrum i.e. the same pytohormone can affect or regulate various processes depending on its concentration and conditions at the sites of action – the receptor sites (Marschner, 1986). The hormone receptors and binding proteins have been identified on membrane surfaces that are specific for some phytohormones (Salisbury and Ross, 1992).

Phytohormones play a dominant role in the regulation of growth and development throughout the plant kingdom. But still we are far from a total understanding of their mode of action at cellular and molecular level. However, several mechanisms or combinations may be operative. Control of genetic expression has been demonstrated for phytohormones at both transcriptional and translational levels.

Phytohormones are used in crops for purposes such as induction of rooting, promotion of abscission, control of fruit development and size, weed control and many other responses (Marschner, 1986; Arteca, 1996). In addition, phytohormones ~~had~~ have been extensively used to induce early flowering, ~~fruit~~ and ripening and to improve yield of crops (Nickell, 1982). The increase in yield was probably due to alteration in assimilate pattern (Addo-Quaye *et al.*, 1986; Subrahmanyam, 1988). They have long

been implicated in assisting in assimilate translocation and in their effect on the sink-source relationship (Patrick, 1982; Thomas, 1986; Patrick and Steains, 1987; Pereto and Beltron, 1987; Khan and Samiullah, 2003).

Auxins, gibberellins, cytokinins, ethylene and abscisic acid are the classical five families of plant growth substances and are now supplemented with brassinosteroids and Jasmonic acid (Dewitte and Onckelen, 2001).

In the following pages, attention is given towards gibberellins and cytokinins as these two phytohormones have been included in the present study.

2.4.1 Gibberellins

Gibberellins (GAs) are chemically closely related with diterpenes, which are themselves members of vast group of naturally occurring compounds in plants called terpenoids. The discovery of gibberellins dates from 1898, when Korishi, for the first time described "bakanae disease" (foolish seedling) of rice with characteristics symptoms of tall spindy plants (Arteca, 1996).

In 1926, Kursowa ~~for the~~ first reported gibberellin from cell culture of *Gibberella fujikuroi*. In 1938, Yabuta and Sumiki were successful in isolating a small quantity of highly active crystalline material from sterile culture filtrates and was given the name "gibberellin A". In 1954, British researchers (Brain *et al.*, 1954) identified and chemically characterized a pure compound from culture – filtrates of *Gibberella fujikuroi*. They called this new substance "gibberellic acid".

The number of GAs now known from all sources is about 121 (Hedden, 1999). High levels of gibberellins have been found in immature seeds, and cell free extracts from seeds possess the ability to synthesize which are not transported out of the seeds (Takahashi *et al.*, 1991). Young leaves are thought to be major sites of gibberellin synthesis. Roots have also ability to synthesize gibberellins, which are transported to shoots via xylem sap (Salisburry and Ross, 1992). Transport of exogenously applied GAs occurs in phloem as noticed by McComb (1964), ~~while~~ Chin *et al.* (1967) reported that the movement of applied GA is related to carbohydrate transport within plant.

Exogenous application of GAs has been shown to relieve certain types of dormancy including physiological dormancy, photodormancy and thermodormancy

(Hartmann *et al.*, 1990), and to promote flowering in a variety of plant species under non-inductive conditions (Zeevaart, 1983; Harkess and Lyons, 1994). Gibberellins stimulate α–amylase and other hydrolytic enzymes promoting hydrolysis of storage reserves (Yomo, 1960; Paleg, 1960a, b).

The influence of gibberellins include parthenocarpic fruit development, senescence, promote cell growth, increase cell wall plasticity, stem elongation, growth of whole plant (Salisbury and Ross, 1992; Taiz and Zeiger, 1998). Cell division in shoot apex, especially in the more basal meristematic cells from which develop the long files of cortex and pith cells (Sachs, 1965). Exogenous application of GA_3 stimulates photosynthetic rate and activity of ribulose biphosphate carboxylase/oxygenase (Wareing *et al.*, 1968; Hoad *et al.*, 1977; Arteca and Dong, 1981; Naidu and Swamy, 1995), phloem loading (Baker, 1985), increase in rate of transpiration and stomatal aperture (Linvine and Vaasida, 1965), relative growth rate (Arteca *et al.*, 1985, 1991), and inhibits adventitious root formation (Salisbury and Ross, 1992; Arteca, 1996, Taiz and Zeiger, 1998). It has been reported that exogenous application of GA accelerated the seed germination (Karseen *et al.*, 1983; 1987; Groot and Karssen, 1987; 1992; Groot *et al.*, 1988; Mayer and Mayber, 1989; Takahashi, 1992; Arularasu and Sambandamurthi, 1999; Naidu, 2001). Considering the numerous effects of gibberellins, it seems logical that they would be used in commercial applications.

2.4.2 Cytokinins

Cytokinins are substituted adenine compounds that promote cell division and other growth regulatory functions in same manner as kinetin i.e. 6-furfurylaminopurine (Arteca, 1996).

The discovery of this group of plant growth hormones came from work concerned with *in vitro* Studies by Haberlandt in 1913 demonstrated that an unknown compound present in vascular tissues of various plants stimulated cell division that caused cork-cambium formation and wound healing in cut potato tubers. This discovery was apparently the first demonstration that plants contain compounds now called cytokinins (Salisburry and Ross, 1992). Miller *et al.* (1955b) found that a very active compound obtained from aged or autoclaved herring sperm

deoxyribonucleic acid (DNA). They named the compound kinetin (6-furfuryl amino purine) because of its ability to promote cell division or *Cytokinesis* in pith tissue (Miller *et al.*, 1955a). Further it was found that kinetin also could be formed from DNA degradation products (Hall and deRopp, 1955). Moreover, numerous cytokinins have been discovered and shown to be ubiquitous in plant kingdom. The chemistry and biological activity of more than 200 natural and synthetic cytokinins was reviewed by Matsubara (1990).

Cytokinin is involved in the regulation of photosynthetic rate and source/sink balance. In addition, cytokinins in root is directly proportional to nitrogen supply (Sameulson *et al.*, 1992; Samuelson and Larsson, 1993; Wagner and Beck, 1993; Takei *et al.*, 2001). Movement of cytokinins in transpiration stream from the roots to shoots stimulates the expression of photosynthetic genes consequently rubisco enzyme (Lerbs *et al.*, 1984), light harvesting chlorophyll a/b binding protein (Flores and Tobin, 1989) and phosphoenolpyruvate carboxylase (Suzuki *et al.*, 1994). Cytokinins delay leaf senescence (Van staden *et al.*, 1988; Gan and Amasino, 1995; Jordi *et al.*, 2000) and offset effects of sugars and light (Wingler *et al.*, 1998; Jordi *et al.*, 2000). Application of cytokinin can mimic the nitrogen-dependent regulation of gene expression in photosynthesis (Sugiharto *et al.*, 1992), cell cycling (Soni *et al.*, 1995; Riou-Khamlichi *et al.*, 1999) and translation machinery (Suzuki *et al.*, 1994).

The major site of the biosynthesis of cytokinin is believed to non-photosynthetic tissues such as root tips (Feldman, 1975; Jameson *et al.*, 1987), apical meristems (Koda and Okazawa, 1980) and immature seeds (Blackwell and Horgam, 1994). It also has been reported that cytokinin synthesis occurs in stems and leaves (Chen *et al.*, 1985). The response which are elicited by cytokinins involved in cell and organ enlargement, delay of senescence, stomatal opening and closing, bud and shoot development, preferential translocation of nutrients and organic substances (Arteca, 1996). Cytokinins play their role in activation of cell growth in leaves (Kulaeva *et al.*, 1996) and promote chloroplast differentiation, and retard leaf senescence (Kulaeva, 1973; Kulaeva *et al.*, 1996; Selivankina *et al.*, 2001).

2.5 Response of crops to plant growth regulators

The plant growth regulators have gained wide acceptance for optimizing the yield of plants by modifying growth, development and stress behaviour. Several investigations have shown the effect of these compounds on plant growth, development or of primary metabolism (Pharis and King, 1985; El-Keltawi and Croteau, 1987; Naiem *et al.*, 1987; Naidu and Swamy, 1995; Gocal, 2001; Pandey *et al.*, 2001).

The available literature on the effect of plant growth regulators particularly of gibberellic acid and cytokinin on the performance of crops has been reviewed in the following pages.

Gaurdia and Benlloch (1980) observed marked increase in plant height when sunflower plants (*Helianthus annuus* L.) were treated with 10µl of GA_3. However, they could not observe any appreciable enhancement in dry matter of the same crop with the application of GA_3. Erkam and Bengerth (1980) reported that gibberellins increased photosynthesis process of pepper (*Capsicum annuum* L.).

Arteca and Dong (1981) reported that photosynthetic rates increased about 40 to 50% with 1.4µM GA_3 treatment to the roots of tomato (*Lycopersicum esculatum* L.). Karnick *et al.* (1981) conducted trials on shoorapunkha (*Tephrosia purpurea* Pers.). They noted that plants treated with GA, flowered earlier and had increased leaves/shoot and plant contents including alkaloids, glycosides, and carbohydrates. Venkataramiah and Swamy (1981) reported that the foliar application of GA_3 (10, 100, 200 and 500 ppm) enhanced plant growth, internodal elongation and net assimilation rate in red sanders (*Pterocarpus sanlalinus* L.). Application of 500 ppm GA_3 gave the highest values when compared with the rest of concentrations.

Nandi and Chatterjee (1982) analysed dautra (*Dautra innoxia*) for total alkaloid and nitrogenous contents in response to GA_3 treatments. They found that GA_3 at 25 or 200 mµg/ml increased alkaloid biosynthesis, all three types of N contents (total N, protein N and soluble N), rate of extension growth during the vegetative stage and total number of flowers/truss.

Nandwal and Bharti (1982) working on pea (*Pisum sativum* L.) reported that plant height, fresh and dry weights and yield components increased with increasing

application of kinetin up to 44 × 10^{-9} M. Whilst, efficiency of nodules to fix nitrogen was maximum with the application of kinetin at 22 × 10^{-9} M. Mostafa *et al.* (1984) studied the effect of growth regulators on dautra (*Dautra innoxia*). They showed that kinetin increased leaf alkaloid content, ~~however~~ but GA had an adverse effect on the alkaloid content.

Abdalla *et al.* (1985) studied the influence of ~~spray of~~ kinetin at 12.5, 25.5 and 100 ppm on annua (*Adonis aulumalis* L.). It was reported that kinetin increased plant height, stem diameter, branch number, plant weight, flower number and weight and fruit weight and hastened flowering. Increases were proportional to the concentrations.

Arteca *et al.* (1985) observed that application of GA_3 on *Pelargonium* plants stimulated relative growth rate and reduced transpiration rate. However, net photosynthetic rate and total chlorophyll content were unaffected.

Minu (1986) studied effect of different concentrations of Kn (10 to 100 ppm) on eleven cultivars of lamk (*Leucaena lecocephala*). It was found that for noted parameters, some cultivars showed positive response and some exhibited inhibition in all concentrations. However, one or more length parameters, fresh and dry weights were promoted by lower concentrations only.

Gorgiev and Cvetanovske (1987) reported that GA_3 application at 60 ppm increased dry matter production depletion of chlorophyll contents, increased content of carotenoids at rosette and maturity stage, but decreased it at flowering. ~~Whilst,~~ contents of chloroplast pigments decreased during growth of poppy (*Papaver somniferum* L.).

El-Keltawi and Croteau (1987) observed influence of cytokinins on growth and essential oil content of peppermint (*Mentha piperita*) and spearmint (*Mentha spicata*). They reported that foliar applied cytokinins at 1 to 10 ppm showed promoting effect on growth and essential oil yield. The increase in growth and essential oil yield was up to two fold on fresh weight basis in comparison with the control.

Raghava and Murty (1988) in a study on cape-gooseberry (*Physalis peruviana* and *Physalis angulata*) reported that the total fresh and dry weights of plants

increased by application of all concentrations of GA_3 (100, 200 or 500 ppm) and kinetin (10, 25 or 50 ppm).

Sharma *et al.* (1988) studied the effect of spray application of GA_3 (50, 100 and 200 ppm) on bergomint (*Mentha citrata* Ehrh). They reported that the crop showed increasing trend in herb and oil yields as well as yield attributing characteristics, viz. height and number of branches as the result of the GA application. Increase in herb yield under 200 ppm of GA_3 compared with 0, 50 and 100 ppm was 88.3, 53.9 and 30.8% respectively. Similarly, spraying of 200 ppm of GA_3 improved the yield of essential oil to the extent of 92.8, 55.1 and 30.4% compared with the 0, 50 and 100 ppm respectively. The percentage increase in the linayl acetate was 36.3 at 100 ppm GA_3 in comparison with rest of treatments ~~of GA_3~~.

Vimala (1990) while studying the effect of growth regulators on foliaceous cotyledonary leaves of cummunis (*Ricinus communis* L. and *Cummunis sativus* L.), reported that application of gibberellic acid and kinetin increased fresh weight and amount of total chlorophyll in both species.

Dhru and Gupta (1991) registered the nutrient status of *Nerium oleander* and *Urginea indica* as influenced by growth regulators. It was shown that shoot K contents were highest at fruiting stage (6.22, 6.31 and 6.21%) in plants receiving 100 ppm, 10 ppm 2,4-D and 10 ppm TIBA respectively. In *Urginea indica*, shoot P and K contents were higher for 50 ppm GA_3 and 10 and 100 ppm TIBA.

Vasundhara *et al.* (1992) treated plants of marjoram (*Majorana hortensis* Moench) with GA_3 at 100, 200 and 300 ppm. They found a stimulatory effect on plant height, number of branches and plant spread. GA_3 at 200 ppm was found to increase the fresh herb recovery ~~recording~~ maximum oil yield.

Farooqi *et al.* (1993) observed the effect of foliar application of kinetin (5, 10 and 20 mg/l) on flower and oil production in damasakrose (*Rosa demascena*). They found that application of Kn at 20 mg/l significantly increased number of flowers per plant, flower and oil yield. However, effect on flower weight was not significant. Kinetin application also increased citronellol plus geranyl acetate level in the oil by 13% and 24% over control at 20 mg/l

Singh and Hippalgaonkar (1993) observed the effect of foliar applied kinetin on patchouli (*Pagostemom cablin* Benth.). It was noted that all applied concentrations showed an increase in axillary bud development, number of leaves, total leaf area per plant, herbage yield, chlorophyll content, leaf gland number and oil yield. Among applied concentrations, 0.5×10^{-4} M Kn was found most effective in improving growth and increasing oil yield.

Agarwal *et al.* (1994) observed that uptake of nitrogen, phosphorus and potassium in berseem (*Trifolium alexandrium* L.) was maximum in aboveground parts due to the spray of GA_3 at 50 ppm. Maximum net loss of nutrients through litter and roots was found at 25 ppm of GA_3.

El-Shourbagy *et al.* (1994) recorded an increase in plant height of flax (*Linum usitatissimum* L.) and also an increase in phosphorus, potassium and calcium accumulation in all plant organs under the application of GA_3.

Naidu ad Swamy (1995) studied the effect of foliar application of GA_3 (50, 100 and 200 ppm) on three tree species namely *Dilachemdrene atrovirens*, *Eugenia jembolema* and *Terminalia bellerica*. The results revealed that all applied concentrations of GA_3 increased shoot length, internodal elongation, leaf area, biomass production, chlorophyll content, RUBP carboxylase activity, protein content and rate of photosynthesis in all three species. However, highest concentration of GA_3 was found to be superior than other two concentrations applied.

Farooqi *et al.* (1996) studied the effects of gibberellic acid and kinetin on the performance of sweetworm (*Artemisia annua*). Application of GA_3 at 50 mg/l significantly increased plant height and also increased artemisnin content and yield, 43% and 39% respectively over the control. However, when plants were harvested at maximum flowering stage, plant height and dry weights were increased significantly by application of GA_3 at 25 mg/l while application of 50 mg/l was less effective. Oil yield was also increased by 42% at 25 mg/l of GA_3. The herbage and leaf yield was significantly increased by the application of kinetin at 20 mg/l, but decreased artemisinin content. Application of kinetin at 10 mg/l significantly increasing both oil content and yield.

Bhaskar *et al.* (1997) conducted a trial to study the influence of growth regulators such as TIBA (25, 50 and 100 ppm) and kinetin (50, 100 and 200 ppm) on patchouli (*Pogostemon patchouli*). Maximum fresh herbage (3.23 t/ha) and oil yield (24.44 kg/ha) was found with the application of TIBA at 100 ppm and kinetin at 200 ppm. Both herbage production and oil content showed increasing trend with increase in concentration of each growth regulator alone or in combination.

Jose (1997) studied the effect of GA_3 on piper (*Piper sylvaticum*). It has been found that all applied GA_3 concentrations (25 ppm, 50 ppm or 100 ppm) increased internodal elongation, species and yield. El-Sallami (1997) performed an experiment on narcissus (*Narcissus tazetta*) plants. Application of GA_3 and IBA each at 300 ppm, gave the highest values for number and fresh weight of leaves per plant, length of panicle as well as earliest flowering. GA_3 (200 ppm) gave the highest percentage contents of N and P in leaves. However, all applied concentrations of GA_3 decreased chlorophyll and carbohydrate contents.

Premabatidevi (1998) observed that foliar application of GA_3 and kinetin each at 10 ppm showed significant increase in nitrate reductase and nitrate reductase activities in the leaves of legume (*Parkia juranica* MERR).

Farooqui *et al.* (1999) studied the effects of kinetin and gibberellic acid alone or in combination on pyrethrum (*Crysanthemum cinerariaefolium*). It was reported that kinetin and gibberellic acid alone or in combination enhanced the number of flowers per plant, and seeds treated with GA_3 at 100 ppm showed better germination. The pyrethrin content and pyrethrin yield was increased by 39% and 27%, respectively, over control with the application of kinetin.

Singh *et al.* (1999), working on spearmint (*Mentha spicata*), reported that application of GA_3 and ethrel induced significantly phenotypic changes. Ethrel-treated plants had significantly lower contents of Chl (a+b), Chl a, decreased photosynthetic rate, stomatal conductance, internal transpiration rate and plant height compared with control.

Gupta and Datta (2001), working on chrysanthemum (*Chrysanthemum morifolium*, RAMAT), found that application of GA_3 at 100 mg/l showed maximum increase in plant height, leaf size, stem diameter and flower yield per plant.

Balvanyos *et al.* (2001) observed the effect of kinetin on *Lobelia inflata*. It was noted that kinetin significantly decreased growth and lobeline production and strongly inhibited biomass formation at 5 mg/l.

Borse and Dhumal (2001) observed in a pot trial that GA_3 treatment significantly reduced the spines on leaves and stem of *Solanum khasianum*. Whilst, active principle solasodine content was considerably enhanced with GA_3 over control.

Singh and Misra (2001), studying on spearmint (*Mentha spicata* var. MSS-5), noted an enhanced fresh weight biomass, leaf stem ratio, leaf area, specific leaf weight and chlorophyll content with gibberellin (GA) and ethrel at 1000µg/l. Limonene increased significantly in ethrel and GA treated genotypes.

2.6 Response of crops to mineral nutrients and plant growth regulators in combination

It is well established that in all species of plants growth involves hormonal control. There are increasing evidences that environmental factors such as temperature, day length and water stress may affect endogenous hormone levels. Likewise, deficient and toxic levels of nutrients can affect the concentration of specific hormones, and in turn hormones have the capacity to direct the translocation and accumulation of nutrients in plants (Kuiper, 1988; Kuiper *et al.*, 1989). Further, effects of mineral nutrients on plant growth and yield are most likely caused primarily by their influence on phytohormone balance in the plant. Considering the complex interactions of plant hormones and the multiplicity of plant functions they control, the impact of nutrients on hormones is an important issue (Whenham *et al.*, 1989; Thorsteinsson and Eliasson, 1990; Arshad and Frenkenberger, 1991; Cao *et al.*, 1993).

In the following pages, an effort has been made to review the available literature regarding the combined impact of mineral nutrients and phytohormones on performance of various crops.

Alvim (1960), working on bean (*Phaseolus vulgaris* L.), reported that urea sprays decreased plant height and leaf area when applied alone but had a stimulative effect when applied with gibberellic acid.

Guardia and Benlloch (1980) while studying on sunflower (*Helianthus annuus* L.) reported that application of GA_3 in combination with potassium enhanced plant height maximally as compared to the ~~individual~~ application of GA_3 or potassium alone.

Bangal *et al.* (1982) found that foliar spray of growth regulators (2,4-D, Atrataf, NAA and CCC) and urea affected the grain weight per plant ~~of gram~~ (*Cicer arietinum* L.). Significant increase was observed in seed yield with combined application of NAA (25 ppm) and urea (1%).

Simpson *et al.* (1982) while studying on wheat seedling (*Triticum aestivum* L. cv. SUN9E) reported that growth rate, N concentration and N uptake in roots and shoots and translocation of C to the total root system were increased with kinetin application to NO_3-fed roots compared with NO_3-free roots.

Meward *et al.* (1984), working on chamomile (*Matricaria chamomilla*), concluded that application of N at 300 kg/feddan (convert to ha) in combination with GA_3 at 10–100 ppm or ethephon at 1–10 ppm or cycocel (chlormequate) at 50–500 ppm or diaminozide at 50–500 ppm proved best in respect of growth and essential oil yield.

Grewall and Gill (1986), performing an experiment on paddy (*Oryza sativa* L.), reported that leaf area index and chlorophyll content were increased with foliar spray of NAA and nitrogen. However, a more beneficial effect on grain yield under the low level of N (0 and 60 kg N/ha) was observed. This improvement was associated with number of ear-bearing shoots/plant, number of filled grains/panicle and grain weight.

Sawan *et al.* (1988) observed an enhancement in seed yield of cotton (*Gossypium barbedense* L.) under the combined application of growth regulators (IAA, IBA and NAA) and increasing levels of nitrogen (72, 144 or 216 kg/ha) and phosphorus (36 or 72 kg P_2O_5/ha). Oil percentage was found to be influenced with the application of growth regulators and high P level, and followed an upward trend.

Uppar and Kulkarni (1989) observed that highest yield of sunflower (*Helianthus annuus* L.) was associated with nitrogen application in combination with TIBA (250 ppm).

~~In an observation,~~ Grewal *et al.* (1993) observed a reduction in plant height and leaf area index of mustard (*Brassica juncea* L. Czern & Coss.) by the foliar spray of CCC and ethrel. However, at 50 kg N/ha in combination with 250 ppm CCC or 500

ppm ethrel, the crop retained more leaf area index. Further at 100 kg N/ha, 500 ppm CCC and 1000 ppm ethral proved more beneficial. Chlorophyll content in leaves was significantly improved when CCC (250 and 500 ppm) or ethrel (500 ppm) was applied in combination with 50 and 100 kg N/ha.

Kalita *et al.* (1995) conducted an experiment on green gram (*Vigna radiata* L. Wilczek, cv. AAU-34). They applied 0 (water), P and NAA in different combinations as foliar treatments. The treatment combination 3.0% P_2O_5 + 100 ppm NAA increased dry matter accumulation/plant, nitrogen accumulation/~~in~~ plant, highest seed yield, number of pods/plant and seeds/pod.

A perusal of foregoing review of literature reveals that various plants response not only to applied nutrients but also to ~~their various levels under various agro-climatic conditions. A few reports are also~~ there that phytohormones are potent ~~chemicals for enhancing performance of various crops~~. However, information regarding the interaction ~~effect~~ of mineral nutrients ~~with~~ phytohormones on medicinal plants particularly on *Mentha arvensis* is almost negligible. Therefore, an in depth study on the effect of nitrogen, phosphorus, gibberellic acid and kinetin application alone as well as in combination is highly desirable.

MATERIALS AND METHODS

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MATERIALS AND METHODS

Chapter 3

MATERIALS AND METHODS

The details of the materials used and the methods followed during the course of the six pot experiments (2000 and 2001) are presented in this chapter.

3.1 Experimental material

Suckers of Japanese mint (*Mentha arvensis* L.) were used as experimental material.

3.1.1 Nomenclature

Four commercially cultivated mentha species are available in India. These include Japanese mint (*Mentha arvensis* L.), pipermint or mitcham mint (*Mentha piperita*), spearmint (*Mentha spicata*) and bergamot mint (*Mentha citrata*).

Japanese mint (*Mentha arvensis* L.) is known by various names. In Sanskrit, puthea; Hindi, pudina, podina; English, corn mint; German, minze; Unani and Kashmiri, pudinah; Arabian, putnaj; Japanese, midorihakka.

3.1.2 Botanical description

Mentha a small genus of aromatic perennial herb belongs to family Lamiaceae (Labiatae). These perennial aromatic herbs have been in use by mankind since ancient times but its commercial cultivation in India has been taken up recently.

3.1.2.1 Morphological characters

The Japanese mint (*Mentha arvensis* L.) is erect, branched herb, vigorous in growth and grows up to 1 m height under cultivation with rootstock creeping along or remain under the ground surface. The leaves are lanceolate to oblong, 3-10 cm long, sharply toothed, sessile or shortly petiolated. Flowers are arranged in cyme, which are usually sessile or rarely pendunculate. Flowers are purple and minute in size. Calyx is 2.5-3.0 mm long narrowly deltoid and accuminate, whereas corolla is white to purple, 4-5 mm long. The leaves, stem and calyx bear glandular and non-glandular hair. The glandular heads of these hairs possess volatile oil. Diacytic stomata are present on the lower surface of the leaf.

3.1.3 Habitat

It is cosmopolitan in habitat and found chiefly in warm, dry temperate regions. It is also found at an altitude of about 4000 to 9000 ft in Kashmir.

3.1.4 Medicinal properties and uses

The plant is aromatic. The dried plants are given in the form of "sharbat" or syrup for its cooling and diuretic effects. It is used as an antiseptic, carminative, stomachic and refrigerant. It is considered to be a stimulant and emmeriagogue. Juice of leaves is given in diarrhoea and dysentery. Infusion of leaves is used in rheumatism and indigestion.

3.1.5 Ayurvedic description

Rasa – katu; Guna – laghu, rooksha, teekshna; Veerya – ushna; Vipak – katu.

3.1.6 Physico-chemical properties of oil

The physico-chemical properties, viz. specific gravity (20°C) 0.8942-0.9054, optical rotation (20°C) 0.8942-0.90054, refractive index (20°C) 1.4500-1.4995 have been reported for Indian Japanese mint oil (Gupta, 1995).

3.2 Experimental site

Six pot experiments were conducted in the net house of the Department of Botany, Aligarh Muslim University, Aligarh, India.

3.3 Agro-climatic conditions

Aligarh, a small industrial city, is one of the eighty-three districts of Uttar Pradesh (UP) with an area of 5,024 sq km. It is situated at 27°52'N latitude, 78°51'E longitude and 187.45 m altitude above sea level. It has the characteristic climate of Western Uttar Pradesh (UP), i.e. semi-arid and sub-tropical with ~~vehement~~ dry summers and apathetic winters. The winter extends from the middle of October to the end of March. The summer starts from April to June. In this season, a gradual increase in temperature is recorded, which attains maximum, sometimes up to 46°C, in the month of June. There is a fall in the temperature in December and January that may reach as low as 15°C ~~and~~ to 13°C and the extreme minimum record for any single day is 2°C and 5°C respectively. The average rainfall is about 847 mm. More than 85% of total ~~send down~~ rain is ~~rescued~~ in a short span from June to September and remaining showers are received during winter which is useful for winter crops.

3.4 Meteorological parameters

The meteorological data for the period of all experiments (Figs. 1a, b) were documented at the Meteorological Observatory, Department of Physics, Aligarh Muslim University, Aligarh, India.

3.5 Soil characteristics

Aligarh district has the same soil composition and appearance as that found generally in Western Uttar Pradesh (UP). Different types of soil such as sandy, loam, sandy loam and clay-loam are found in the district. For each experiment, the soil used for filling the pots was collected from various parts of a field at the depth of about 10-15 cm. These samples were blended together and the composite sample was analysed for various physico-chemical characters of the soil. The data obtained for the characteristics of soil are given in Table 1.

3.6 Filling of pots

Each pot (diameter × height – 25×25 cm) was filled with 4 kg homogenous mixture of soil and farmyard manure in the ratio of 3 : 1.

3.7 Planting of suckers

Healthy suckers with equal number of nodes were selected and initially six suckers were planted at equidistant in each pot. The pots were watered slightly after planting.

3.8 Thinning

After 30 days of planting, 3 plants/pot were maintained by thinning.

3.9 Crop protection

In order to check the aphids contagion, an insecticidal spray of Dimecron-100 was done ten days after first sampling and just before flowering.

3.10 Weeding

Weeding was done weekly during the entire crop season to keep the pots free of weeds.

3.11 Irrigation

The crop was irrigated as and when required during the entire crop growth period.

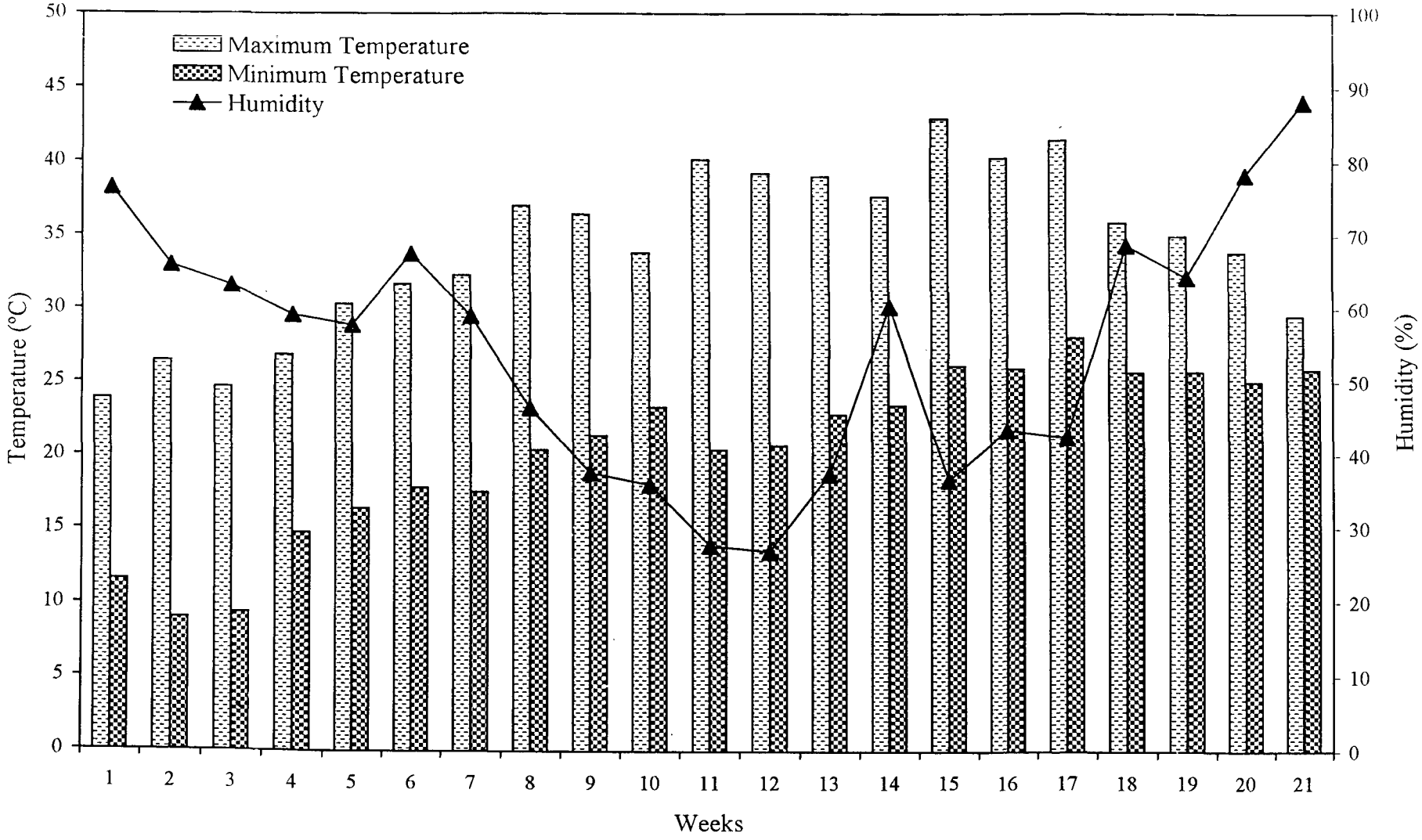

Fig. 1a. Average weekly variation in temperature and relative humidity during the experimental period from 20 February to 15 July 2000.

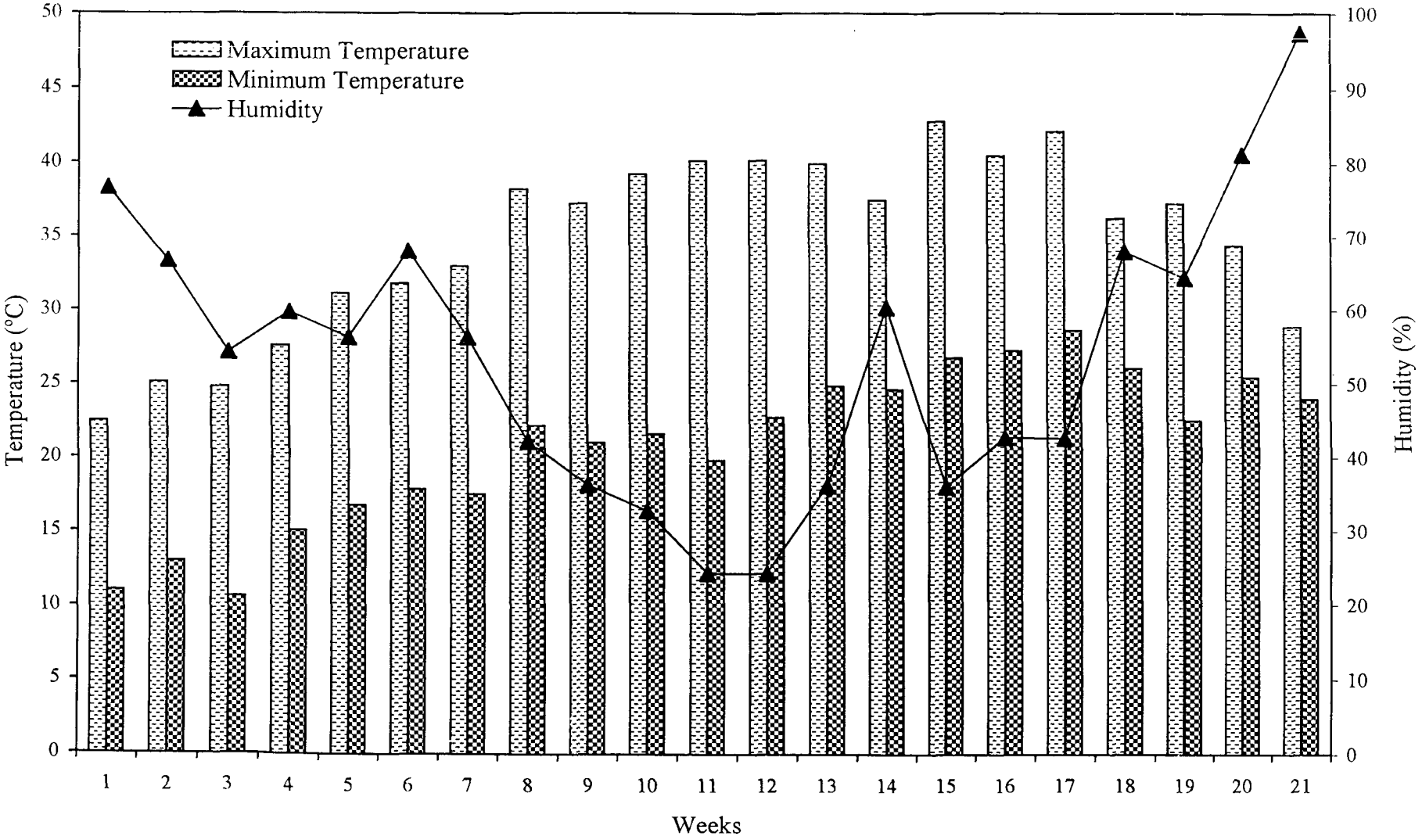

Fig. 1b. Average weekly variation in temperature and relative humidity during the experimental period from 20 February to 15 July 2001.

Table 1. Physico-chemical characteristics of soil used for Experiment 1-6.

Characteristics	Experiment 1	Experiment 2	Experiment 3	Experiment 4	Experiment 5	Experiment 6
Texture	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam
pH (1:2)	7.99	8.03	8.15	8.10	7.98	8.04
EC (1:2) (m mhos/cm)	0.43	0.44	0.48	0.49	0.42	0.41
Available N (kg N/ha)	210	205	218	220	213	217
Available P (kg P/ha)	24.00	26.00	22.00	20.00	28.00	26.00
Available K (kg K/ha)	213.00	217.00	211.00	213.00	220.00	218.00

3.12 Harvesting

Plants were harvested with root along with underground suckers from each pot and were washed thoroughly to remove the adhered soil particles.

3.13 Experiment 1

This pot experiment was conducted according to a simple randomized design during summer season. The aim of this experiment was to investigate the effect of nitrogen on the performance of Japanese mint (*Mentha arvensis* L.). Suckers were planted on 20th February, 2000. Nitrogen (as urea) was applied at the rate of 0 (control), 30 (116 mg/pot), 60 (232 mg/pot), 90 (348 mg/pot) and 120 kg N/ha (464 mg/pot) at 70 days after planting (DAP). A uniform dose of muriate of potash at the rate of 40 kg K/ha (150 mg/pot) was also applied. Each treatment was replicated three times (Table 2). The crop was finally harvested on the 15th July, 2000.

3.14 Experiment 2

This experiment was conducted simultaneously with Experiment 1 according to a simple randomized design.

The aim of this pot experiment was to assess the effect of applied phosphorus (as single superphosphate) on performance of Japanese mint (*Mentha arvensis* L.). The suckers were planted on the 20th February, 2000. The phosphorus was applied at the rate of 0 (control), 10 (99 mg/pot), 20 (198 mg/pot), 30 (297 mg/pot) and 40 kg P/ha (396 mg/pot) at 70 DAP. Potassium (as muriate of potash) was also applied uniformly at the rate of 40 kg K/ha (150 mg/pot) in each pot. Each treatment was replicated thrice (Table 3). The crop was finally harvested on the 15th July, 2000.

3.15 Experiment 3

This pot experiment was conducted concurrently with Experiments 1 and 2 according to simple randomized design. The aim of the experiment was to investigate the effect of foliar spray of GA_3 on the performance of *Mentha arvensis* L. The crop was planted on the 20th February, 2000. Four concentrations of GA_3 at 0 (control), 10^{-4}, 10^{-3} and 10^{-2}M were sprayed on foliage at 70 DAP. There were three replications (Table 4). The crop was finally harvested on the July 15, 2000.

Table 2. Scheme of treatments for Experiment 1.

Treatments	Soil-applied N (kg N/ha)
N_0 (control)	0
N_{30}	30
N_{60}	60
N_{90}	90
N_{120}	120

N.B. : Nitrogen treatments were applied at 70 days after planting (DAP).

Table 3. Scheme of treatments for Experiment 2.

Treatments	Soil-applied P (kg N/ha)
P_0 (control)	0
P_{10}	10
P_{20}	20
P_{30}	30
P_{40}	40

N.B. : Phosphorus treatments were applied at 70 DAP.

3.16 Experiment 4

This pot experiment was carried out together with Experiments 1-3 in the same season. The aim of the experiment was to observe the effect of kinetin (6-furfurylamino-purine) on the performance of Japanese mint (*Mentha arvensis* L.). The suckers were planted on the 20th February, 2000. The crop was sprayed with kinetin at the rate of 0 (control), 10^{-6}, 10^{-5} and 10^{-4}M at 70 DAP. The design of the experiment was simple randomized. Each treatment was replicated thrice (Table 5). The crop was finally harvested on the 15th July, 2000.

3.17 Experiment 5

This pot experiment was conducted according to a factorial randomized design in the summer season. The experiment was based on the findings of Experiments 1, 3 and 4. The aim of this experiment was to study the interaction effect of soil-applied nitrogen with exogenous supply of GA_3 or Kn on performance of *Mentha arvensis* L. The crop was planted on the 20th February, 2001. Four rates of urea nitrogen (0, 60, 90 and 120 kg N/ha) were applied to the soil at 70 DAP. The crop was sprayed with five rates of phytohormones (0, 10^{-5} and 10^{-4}M GA_3 and 10^{-6} and 10^{-5}M Kn) at the same stage (70 DAP). Plants grown with no exogenous nutrients, sprayed with double distilled water (W_0) constituted the control. Each treatment has three replications (Table 6). The crop was finally harvested on the 15th July, 2001.

3.18 Experiment 6

This pot experiment was carried out simultaneously with Experiment 5 according to a factorial randomized design. This experiment was based on the findings of Experiments 2, 3 and 4. The aim of this experiment was to study the interaction effect of phosphorus with GA_3 or Kn, on the performance of *Mentha arvensis* L. The crop was planted on 20th February, 2001.

Phosphorus was applied at the rate of 0, 20, 30 and 40 kg P/ha at 70 DAP. At the same stage, foliar sprays of GA_3 (10^{-5} and 10^{-4}M) and Kn (10^{-6} or 10^{-5}M) were given to the plants. Control group of plants was grown with no exogenous nutrient and sprayed with double distilled water (W_0). The crop was planted on the 20th February, 2001. There were three replicates for each treatment (Table 7). The crop was finally harvested on the 15th July, 2001.

Table 4. Scheme of treatments for Experiment 3.

Treatments	Leaf-applied GA_3 (M)
W_0 (control)	0.0 (water)
10^{-4}M GA_3	0.0001
10^{-3}M GA_3	0.001
10^{-2}M GA_3	0.01

N.B. : Gibberellic acid treatments were applied at 70 DAP.

Table 5. Scheme of treatments for Experiment 4.

Treatments	Leaf-applied Kn (M)
W_0 (control)	0.0 (water)
10^{-6}M Kn	0.000001
10^{-5}M Kn	0.00001
10^{-4}M Kn	0.0001

N.B. : Gibberellic acid treatments were applied at 70 DAP.

Table 6. Scheme of treatments for Experiment 5.

Soil application	Foliar application				
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn
N_0					
N_{60}					
N_{90}					
N_{120}					

N.B. : Soil and foliar treatments were applied at 70 DAP.

Table 7. Scheme of treatments for Experiment 6.

Soil application	Foliar application				
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn
P_0					
P_{20}					
P_{30}					
P_{40}					

N.B. : Soil and foliar treatments were applied at 70 DAP.

3.19 Determinations

Samples of three plants from each pot were taken out at 90, 105, 120, 135 and 150 DAP to study the growth, physiological and yield characteristics.

3.19.1 Growth characteristics

The following growth characteristics on per plant basis were studied:

1. Plant height
2. Root length
3. Leaf area
4. Leaf area ratio
5. Specific leaf area
6. Leaf dry weight
7. Specific leaf weight
8. Stem dry weight
9. Aboveground plant dry weight
10. Underground plant fresh weight
11. Underground plant dry weight

3.19.2 Physiological characteristics

3.19.2.1 Photosynthetic characteristics

1. Chlorophyll content
2. Chlorophyll harvest
3. Photosynthetic rate
4. Stomatal conductance
5. Photosynthetic water use efficiency

3.19.2.2 Nutrient contents in plants

1. Nitrogen
2. Phosphorus
3. Potassium

3.19.2.3 Nutrient uptake

1. Nitrogen
2. Phosphorus
3. Potassium

3.19.3 Yield characteristics

On per plant basis, the following parameters were studied:

1. Leaf number
2. Branch number
3. Leaf yield
4. Stem yield
5. Herb yield
6. Oil content
7. Oil yield

3.19.4 Sampling techniques

3.19.4.1 Growth characteristics

3.19.4.1.1 Plant height and root length

After washing of plant samples, shoot length and root length were measured.

3.19.4.1.2 Fresh weight of plant parts

Sampled plants were divided into aboveground and underground parts. The former part was further divided into stem and leaves. The recorded weight of each plant part was treated as fresh weight of that part. The herb yield was computed on the basis of fresh weight of stem and leaves.

3.19.4.1.3 Dry weight of plant parts

The plant parts, of which fresh weight was recorded, were dried in hot air oven at 80°C for two days. The dried parts were weighed and the weight was recorded as dry weight of different plant parts.

3.19.4.1.4 Number of branches and leaves per plant

Branch number and leaf number of each plant was counted respectively.

3.19.4.1.5 Leaf area per plant

Leaf area (LA) was determined by gravimetric method. Leaf area of about 10% leaves from each sample was determined by tracing the leaves on a graph sheet and area of these leaves was recorded. The leaf area per plant was computed on the basis of the dry weight of those leaves for which the area was determined and total dry weight of leaves of a plant using the formula:

$$LA = \frac{LA_1}{W_1} \times W_2$$

where LA_1 = leaf area of the leaves traced on graph paper

W_1 = Dry weight of leaves for which leaf area was traced on graph paper

W_2 = Total leaf dry weight/plant

3.19.4.1.6 Leaf area ratio

Leaf area ratio was determined according to Radford (1967):

$$LAR = \frac{\text{Leaf area}}{\text{Dry weight of shoot}}$$

3.19.4.1.7 Specific leaf area

Specific leaf area (SLA) represents leaf area of unit leaf biomass and was obtained using the formula:

$$SLA = \frac{\text{Leaf area}}{\text{Leaf dry weight}}$$

3.19.4.1.8 Specific leaf mass

Specific leaf weight (SLW) was calculated by dividing the leaf dry weight by the leaf area using the formula:

$$SLW = \frac{\text{Leaf dry weight}}{\text{Leaf area}}$$

3.19.4.2 Physiological characteristics

3.19.4.2.1 Photosynthetic characteristics

3.19.4.2.1.1 Photosynthetic rate and stomatal conductance

Rate of photosynthesis, stomatal conductance in leaves were measured with the LiCOR-6200 Portable Photosynthesis System (Nebraska, USA). These measurements were made on fully expanded leaves of the main branch of plants. All the measurements were made on cloudless clear days between 11.00 and 12.00 solar time.

3.19.4.2.1.2 Photosynthetic water use efficiency

Photosynthetic water use efficiency was calculated by dividing rate of photosynthesis by stomatal conductance, as described by Das *et al.* (1999).

3.19.4.2.1.3 Chlorophyll content

Estimation of chlorophyll contents a, b and total chlorophyll was done by adopting the method of Hiscox and Israelstam (1979). The details of the method are described as follows.

3.19.4.2.1.3.1 Extraction

Freshly plucked leaves (100 mg) were slashed into pieces and collected in the tubes containing 7.0 ml dimethyl sulphoxide (DMSO). The test tubes were covered with black paper and incubated at 55°C for 45 minutes. The solution was transferred to a graduated tube and the final volume was made up to 10.0 ml with DMSO.

3.19.4.2.1.3.2 Chlorophyll estimation

A 3 ml sample of chlorophyll extract was transferred to a cuvette and absorbance was taken at 645 and 663 nm on the spectrophotometer (Elico SL-171, India).

3.19.4.2.1.3.3 Calculation of chlorophyll concentration

The chlorophyll content was calculated following the equation given by Arnon (1949).

$$\text{Chlorophyll a (mg/g leaf fresh weight)} = (12.7 \times OD_{663}) - (2.69 \times OD_{645}) \times \frac{V}{1000 \times W}$$

$$\text{Chlorophyll b (mg/g leaf fresh weight)} = (22.9 \times OD_{645}) - (4.68 \times OD_{663}) \times \frac{V}{1000 \times W}$$

$$\text{Total Chlorophyll (mg/g leaf fresh weight)} = (20.2 \times OD_{645}) + (8.02 \times OD_{663}) \times \frac{V}{1000 \times W}$$

where V = volume of extract

W = weight of leaf taken

3.19.4.2.1.4 Chlorophyll harvest

The chlorophyll harvest was determined by using the formula:

Chlorophyll harvest = chlorophyll content × leaf area per plant

3.19.4.2.1.5 Nutrient content

3.19.4.2.1.5.1 N, P and K concentrations in plants

The dried plant material collected at different sampling stages was used for estimation of N, P and K content.

3.19.4.2.1.5.1.1 Digestion of plant samples for N, P and K content

The digestion of plant material was done by following the method of Lindner (1944).

100 mg oven dried plant powder from each sample was transferred to a 50 ml Kjeldahl flask to which 2 ml sulphuric acid was added. The content of flask was heated on the temperature controlled assembly for about 2 hours to allow complete reduction of nitrates in plant material by the organic matter itself. As a result, the contents of the flask turned black. After cooling the flask for about 15 minutes, 0.5 ml 30% H_2O_2 was added followed by heating for another 15 minutes. The process was repeated till the contents of the flask turned colourless. The peroxide digested material was transferred from Kjeldahl flask to 100 ml volumetric flask with three washings with double distilled water (DDW). The volume of the flask was made up to mark with DDW. The peroxide digested material was used for the estimation of N, P and K.

3.19.4.2.1.5.1.2 Estimation of nitrogen

Nitrogen was estimated according to the method of Lindner (1944). A 10 ml aliquot of the digested material was taken in a 50 ml volumetric flask. To this, 2 ml of 2.5 N NaOH and 1 ml of 10% $NaSiO_2$ solution were added which neutralize excess of acid and prevent turbidity respectively. The volume of the solution was made up to the mark with DDW. In a 10 ml graduated test tube, 5 ml of the solution was taken and 0.5 ml of Nessler's reagent was added. The final volume was made with DDW. The content of the tube was allowed to stand for 5 minutes for maximum colour development. Then the solution was transferred to a colorimetric tube and optical density (O.D.) was read at 525 nm with the help of spectrophotometer (Elico SL-171, India).

3.19.4.2.1.5.1.2.1 Standard curve for nitrogen

50 mg ammonium sulphate was dissolved in 1 litre DDW. From this solution, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0 ml was pipetted to ten different test tubes. The solution in each test tube was diluted to 5 ml with DDW. In each test tube 0.5 ml of Nessler's reagent was added. After 5 minutes, the optical density was read at 525 nm on a spectrophotometer (Elico SL-171, India). A blank was run simultaneously with each set of determination. Standard curve was plotted using different concentrations of ammonium sulphate solution versus optical density (O.D.) and with the help of this standard curve, the amount of nitrogen present in the sample was determined on dry weight basis.

3.19.4.2.1.5.1.3 Estimation of phosphorus

The method of Fiske and Subba Row (1925) was used to estimate the total content of phosphorus in the digested material. A 5 ml aliquot was taken in a 10 ml-graduated test tube and 1 ml of molybdic acid (2.5% ammonium molybdate and 10 N sulphuric acid) was added carefully, followed by the addition of 0.4 ml of 1-amino-2-naphthol-4-sulphonic acid. Volume was made up to 10 ml with DDW. The solution was shaken for 5 minutes and subsequently transferred to a colorimetric tube. The optical density was read at 620 nm on a spectrophotometer. A blank was run simultaneously.

3.19.4.2.1.5.1.3.1 Standard curve for phosphorus

351 mg of potassium dihydrogen orthophosphate was dissolved in sufficient amount of DDW to which 10 ml of 10 N H_2SO_4 was added and then final volume was made to 1000 ml with DDW. From this solution 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0 ml were taken in different test tubes. The solution in each test tube was diluted to 5 ml with DDW. In each tube 1 ml of molybdic acid and 0.4 ml of 1-amino-2-naphthol-4-sulphonic acid were added. After 5 minutes, optical density was read at 620 nm on a spectrophotometer (Elico SL-171, India). A blank was run with each set of determination. Standard curve was plotted using different dilution of potassium dihydrogen orthophosphate solution versus optical density. With the help of the standard curve, the amount of phosphorus present in the sample was determined.

3.19.4.2.1.5.1.4 Estimation of potassium

Potassium was estimated with the help of a flame photometer. After adjusting the filter for potassium in the photometer, 10 ml peroxide digested material was run. A blank was run simultaneously.

3.19.4.2.1.5.1.4.1 Standard curve for potassium

1.91 g of potassium chloride was dissolved in 100 ml DDW, of which 1 ml solution was diluted to 1 litre. The resulting solution was of 10 ppm potassium concentration. From this, 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 ml solution was transferred to 10 vials separately. The solution in each vial was diluted to 10 ml with DDW. The diluted solution of each vial was run separately. A blank was also run with each set of determination. Standard curve was prepared using different dilution of potassium chloride solution versus reading on the scale of galvanometer. The amount of potassium present in sample was determined with the help of a standard curve.

3.19.4.2.1.5.2 N, P and K uptake of plants

The product of nitrogen, phosphorus and potassium contents of a plant at different sampling stages and respective dry matter at these stages were used to calculate N, P and K uptake.

3.19.4.3 Oil content

The oil content was obtained by distilling fresh leaves at each sampling stage. The oil was extracted with the help of Clevenger apparatus.

3.19.4.3.1 Extraction of oil

50 g of fresh leaves were chopped and were left for some time for air dry. The chopped material was packed in a distillation flask and water was added to the packed material upto mark of flask. Heating was supplied by heating mantle. Before heating the distillation flask, water was run into the graduated receiver keeping the tap open until the water overflowed. Air bubbles in the tube were carefully removed by pressing the tube. The distillation was continued at a rate which kept the lower end of the condenser cool, by continuous supply of tap water with the help of rubber tubings. After some time steam was formed in distilling flask. The mixture of water vapour and essential oil passed into the condenser. As distillation proceeded, the distillate

collected in the graduated part of the receiver. The oil being lighter than water and insoluble in it, floated on the top of the receiver.

At the end of 90 minutes, heating was discontinued, the apparatus was allowed to cool for 10 minutes. As soon as the entire quantity of oil had entered the graduated part of receiver the volume was read directly. The measured amount of oil was taken to be the content of essential oil in the leaves. The content of essential oil was expressed as percentage on weight/weight (w/w) basis.

3.19.4.4 Oil yield

The oil yield was obtained by multiplying percent oil content in the leaves, with total leaf fresh weight.

Oil yield = Oil content (%) × Leaf fresh weight

3.20 Statistical analysis

All experimental data were analysed statistically according to the design of the experiment by using analysis of variance. F value was calculated to identify the significance. Least significant difference (LSD) was calculated to separate the means (Gomez and Gomez, 1984). Relationship of a trait with another was drawn by linear regression analysis. The sample ANOVA tables to show the degree of freedom for replication for the six experiments performed are given in Table 8.

Table 8. Models of analysis of variance (ANOVA) for Experiments 1-6.

Source of variation	d.f.	S.S.	M.S.S.	F. value	Significance
		Experiment 1 and 2 (simple randomized design)			
Replication	2				
Treatment	4				
Error	8				
Total	14				
		Experiment 3 and 4 (simple randomized design)			
Replication	2				
Treatment	3				
Error	6				
Total	11				
		Experiment 5 and 6 (factorial randomized design)			
Replication	2				
Soil treatment	3				
Foliar treatment	4				
Interaction	12				
Error	38				
Total	59				

EXPERIMENTAL RESULTS

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EXPERIMENTAL RESULTS

Chapter 4

EXPERIMENTAL RESULTS

4.1 Experiment 1

The Experiment 1 was conducted to select the best nitrogen dose among applied nitrogen doses on *Mentha arvensis* L. The nitrogen was applied at the rate of 0, 30, 60, 90 and 120 kg/ha. Growth characteristics such as plant height, root length, leaf area per plant, leaf area ratio, specific leaf area, leaf dry weight, specific leaf weight, stem dry weight, above ground dry weight per plant and underground fresh and dry weight per plant; physiological characteristics such as chlorophyll content, chlorophyll harvest, photosynthetic rate, stomatal conductance, photosynthetic water use efficiency; nutrient content like N, P and K; nutrient uptake, viz. N, P and K and yield characteristics such as leaf number, branch number, leaf yield, stem yield, herb yield, oil content and oil yield were studied at 90, 105, 120, 135 and 150 days after planting (DAP). The details of the results are described below and summarized in Tables (9-20).

4.1.1 Growth characteristics

Nitrogen treatments affected all growth parameters significantly at all stages, except specific leaf area and specific leaf weight at 120 DAP (Tables 9-13).

4.1.1.1 Plant height

Maximum value was recorded for N_{90} which was equal to that of N_{120} in effect at 105 DAP. The value noted for the control (N_0) was significantly lowest at all stages of crop growth. The per cent increase in plant height resulted from the application of N_{90} was 24.48, 17.50, 45.92, 35.03 and 36.20 over the control at 90, 105, 120, 135 and 150 DAP respectively (Table 9).

4.1.1.2 Root length

Among applied treatments of nitrogen, N_{90} gave maximum value for root length and its effect was equal to that of N_{60} at 105 DAP and that of N_{120} at 135 and 150 DAP, however at 90 DAP the effect of each treatment differed significantly from each other. The control (N_0) gave significantly minimum value at all samplings. Treatment N_{90} gave 45.63, 42.07, 37.50, 38.58 and 44.99 per cent increase in root

length compared with the control at 90, 105, 120, 135 and 150 DAP respectively (Table 9).

4.1.1.3 Leaf area per plant

Treatment N_{90} gave ~~maximum~~ value and was equal in effect to N_{120} at 120 DAP. The lowest value was noted for the control (N_0). The per cent increase in leaf area due to N_{90} over the control was 78.80, 78.91, 33.99, 32.04 and 40.61 at 90, 105, 120, 135 and 150 DAP respectively (Table 10).

4.1.1.4 Leaf area ratio

Treatment N_{90} at 90, 105 and 150 DAP, and N_{120} at 120 and 135 DAP gave ~~maximum~~ values. Both treatments, viz. N_{90} and N_{120} were equally effective at all stages and also with N_{60} at 135 and 150 DAP. On the other hand, the control (N_0) was recorded with lowest effect at all samplings. The per cent increase in leaf area ratio due to N_{90} over the control was 25.03, 32.69, 12.44, 7.06 and 12.30 at 90, 105, 120, 135 and 150 DAP respectively (Table 10).

4.1.1.5 Specific leaf area

The effect of nitrogen application was significant only at 90, 105, 135 and 150 DAP. Treatment N_{90} gave ~~maximum~~ value at 105, 135 and 150 DAP, however, its effect was ~~at~~ par with that of N_{60} and N_{120} at 105 and 150 DAP and also with that of N_{30} at 135 DAP. At 90 DAP, treatment N_{120} proved most effective. The per cent increase in specific leaf area due to N_{90} over the control was 18.95, 22.57, 4.76 and 8.32 at 90, 105, 135 and 150 DAP respectively (Table 10).

4.1.1.6 Leaf dry weight per plant

The application of N_{90} resulted in ~~maximum~~ value and its effect was equal to that of N_{120} at 105, 135 and 150 DAP but at 90 and 120 DAP its value differed significantly from other treatments. The control showed significantly ~~lowest~~ effect at all stages. The per cent increase in leaf dry weight ~~resulted~~ from application of N_{90}, over the control was 54.32, 45.97, 34.91, 25.84 and 29.82 at 90, 105, 120, 135 and 150 DAP respectively over the control (Table 11).

4.1.1.7 Specific leaf weight

Specific leaf weight was affected by nitrogen treatments significantly at all stages except at 120 DAP. The control gave ~~maximum~~ value at all stages, however its

Table 9. Effect of nitrogen on plant height and root length of *Mentha arvensis* L. at five growth stages.

Treatments (kg N/ha)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Plant height (cm)		
N_0	31.33	40.00	42.83	55.67	55.33
N_{30}	33.70	42.50	48.17	59.00	57.17
N_{60}	34.33	46.33	52.00	65.50	64.17
N_{90}	39.00	47.00	62.50	75.17	74.00
N_{120}	38.33	44.00	57.33	71.67	69.83
C.D. at 5%	0.61	1.73	1.43	1.81	1.91
			Root length (cm)		
N_0	11.33	12.67	16.00	19.00	18.67
N_{30}	12.40	14.60	18.00	20.33	19.87
N_{60}	13.25	17.80	19.67	21.33	20.96
N_{90}	16.50	18.00	22.00	23.33	23.17
N_{120}	15.50	17.35	21.00	22.67	22.38
C.D. at 5%	0.64	0.47	0.44	0.49	0.80

Table 10. Effect of nitrogen on leaf area, leaf area ratio and specific leaf area of *Mentha arvensis* L. at five growth stages

Treatments (kg N/ha)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Leaf area (cm^2 $plant^{-1}$)		
N_0	434	920	2959	5375	5025
N_{30}	508	1172	3212	5765	5438
N_{60}	588	1364	3604	6358	6170
N_{90}	776	1646	3965	7097	7065
N_{120}	733	1587	3921	6987	6761
C.D. at 5%	22	55	72	23	29
			Leaf area ratio (cm^2g^{-1})		
N_0	287.51	450.87	511.10	604.61	570.33
N_{30}	287.09	503.14	511.49	598.06	564.73
N_{60}	309.67	554.38	556.16	640.27	621.93
N_{90}	358.95	598.26	574.68	636.58	634.24
N_{120}	357.50	576.97	576.56	645.15	624.86
C.D. at 5%	18.94	33.32	21.60	24.88	21.81
			Specific leaf area (cm^2g^{-1})		
N_0	276.43	308.72	499.04	546.79	535.11
N_{30}	263.29	347.87	498.78	560.82	546.02
N_{60}	276.23	355.15	493.01	572.78	568.62
N_{90}	328.81	378.39	495.66	572.83	579.61
N_{120}	370.15	373.33	502.00	570.83	562.48
C.D. at 5%	26.70	29.03	NS	14.54	17.34

effect was at par with that of N_{60} at 90 DAP and N_{30} at 150 DAP. The lowest value was recorded with N_{90} at all stages, except 90 DAP at which N_{120} gave the minimum value. The per cent decrease in specific leaf weight due to N_{90} in comparison with the control was 17.43, 22.72, 5.17 and 8.72 at 90, 105, 135 and 150 DAP respectively (Table 11).

4.1.1.8 Stem dry weight per plant

Among applied treatments, N_{90} gave highest value and its effect was equal with that of N_{120} at 90 DAP. However, at 105, 120, 135 and 150 DAP the effect of each treatment was significant. Minimum value was recorded for the control (N_0) at all stages. Treatment N_{90} gave 51.05, 34.80, 19.17, 25.42 and 26.45 per cent higher value for stem dry weight than the control at 90, 105, 120, 135 and 150 DAP respectively (Table 12).

4.1.1.9 Aboveground plant dry weight

Of nitrogen treatments, maximum value was given by N_{90} and its effect was equal to that of N_{120} at 120, 135 and 150 DAP. Treatment N_{90} gave 37.77, 41.43, 27.13, 29.43 and 28.36 per cent increase in plant dry weight compared with the control at 90, 105, 120, 135 and 150 DAP respectively (Table 12).

4.1.1.10 Underground plant fresh weight

Treatment N_{90} gave highest value for underground plant fresh weight at all stages but at 135 and 150 DAP its effect was equal to that of N_{120}. However at 90, 105 and 120 DAP, the effect of each treatment was significant. Minimum value was recorded for the control at all stages. The underground plant fresh weight increased due to N_{90} over the control was 66.67, 55.36, 28.06, 31.99 and 33.08 per cent at 90, 105, 120, 135 and 150 DAP respectively (Table 13).

4.1.1.11 Underground plant dry weight

Maximum value was noted for N_{90} and was at par with that of N_{120} at 135 and 150 DAP. On the other hand, the minimum value was given by the control (N_0) at all stages. The increase in underground plant dry weight due to N_{90} over the control was 50.48, 55.64, 28.51, 32.10 and 33.33 per cent at 90, 105, 120, 135 and 150 DAP respectively (Table 13).

Table 11. Effect of nitrogen on leaf dry weight per plant and specific leaf weight of *Mentha arvensis* L. at five growth stages.

Treatments (kg N/ha)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Leaf dry weight (g plant^{-1})		
N_0	1.57	2.98	5.93	9.83	9.39
N_{30}	1.93	3.37	6.44	10.28	9.96
N_{60}	2.13	3.84	7.31	11.10	10.85
N_{90}	2.36	4.35	8.00	12.37	12.19
N_{120}	1.98	4.25	7.81	12.24	12.02
C.D. at 5%	0.06	0.15	0.16	0.17	0.12
			Specific leaf weight (mg cm^{-2})		
N_0	3.62	3.24	2.00	1.83	1.87
N_{30}	3.34	2.88	2.00	1.78	1.83
N_{60}	3.54	2.81	2.03	1.74	1.76
N_{90}	3.04	2.64	2.02	1.74	1.72
N_{120}	2.70	2.68	1.99	1.75	1.78
C.D. at 5%	0.12	0.11	NS	0.04	0.07

Table 12. Effect of nitrogen on stem dry weight and aboveground dry weight of *Mentha arvensis* L. at five growth stages.

Treatments (kg N/ha)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Stem dry weight (g plant^{-1})		
N_0	1.43	2.04	5.79	8.89	8.81
N_{30}	1.77	2.33	6.28	9.64	9.63
N_{60}	1.90	2.46	6.48	9.93	9.92
N_{90}	2.16	2.75	6.90	11.91	11.14
N_{120}	2.05	2.62	6.80	11.27	10.82
C.D. at 5%	0.19	0.04	0.04	0.03	0.06
			Aboveground plant dry weight (g plant^{-1})		
N_0	3.10	5.02	11.72	18.79	18.23
N_{30}	3.70	5.70	12.72	19.97	19.62
N_{60}	4.04	6.30	13.79	21.10	20.80
N_{90}	4.45	7.10	14.90	24.32	23.40
N_{120}	4.03	6.87	14.61	23.55	22.90
C.D. at 5%	0.21	0.18	0.38	1.10	0.95

Table 13. Effect of nitrogen on underground plant fresh weight and dry weight of *Mentha arvensis* L. at five growth stages.

Treatments (kg N/ha)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Underground plant fresh weight (g plant^{-1})		
N_0	4.20	5.60	10.62	14.60	14.33
N_{30}	5.10	6.55	11.47	16.63	16.43
N_{60}	5.70	7.50	12.25	18.00	17.80
N_{90}	7.00	8.70	13.60	19.27	19.07
N_{120}	6.70	8.33	13.45	19.15	18.95
C.D. at 5%	0.10	0.11	0.11	0.19	0.23
			Underground plant dry weight (g plant^{-1})		
N_0	1.00	1.24	2.35	3.24	3.18
N_{30}	1.13	1.45	2.54	3.69	3.65
N_{60}	1.26	1.66	2.72	4.00	3.95
N_{90}	1.55	1.93	3.02	4.28	4.24
N_{120}	1.48	1.85	2.98	4.25	4.21
C.D. at 5%	0.03	0.02	0.02	0.04	0.05

4.1.2 Physiological characteristics

4.1.2.1 Photosynthetic characteristics

Effect of nitrogen on all photosynthetic characteristics at all stages studied was significant (Tables 14-15).

4.1.2.1.1 Chlorophyll content

Each treatment of nitrogen gave higher value for chlorophyll content than the control (N_0). However maximum value was recorded for N_{90} and its effect was equal to that of N_{60} at 90 DAP but at 105, 120, 135 and 150 DAP the value recorded for all treatments differed significantly from each other. The per cent increase in chlorophyll content resulted from the application of N_{90} was 17.27, 44.23, 32.92, 23.57 and 29.43 over the control at 90, 105, 120, 135 and 150 DAP respectively (Table 14).

4.1.2.1.2 Chlorophyll harvest per plant

Maximum and minimum value was recorded for N_{90} and the control (N_0) respectively at all sampling stages. Treatment (N_{90}) resulted in 121.16, 158.70, 78.10, 62.71 and 82.87 per cent increase in chlorophyll harvest over the control at 90, 105, 120, 135 and 150 DAP respectively (Table 14).

4.1.2.1.3 Photosynthetic rate

Maximum value was recorded with N_{90} at all growth stages. Its effect was equal to that N_{120} at 105 DAP. Significantly lowest value was recorded for the control (N_0) at all stages of sampling. The per cent increase in rate of photosynthesis due to N_{90} over the control was 24.89, 31.63, 24.08, 20.17 and 22.80 at 90, 105, 120, 135 and 150 DAP respectively (Table 15).

4.1.2.1.4 Stomatal conductance

Treatment N_{90} showed highest effect on stomatal conductance at all stages, at 90, 105, 135 and 150 DAP, its effect was equal to that of N_{120}. On the other hand, the control (N_0) showed lowest effect. The per cent increase in stomatal conductance resulted from the application of N_{90} over the control was 10.34, 13.95, 9.30, 8.63 and 9.09 at 90, 105, 120, 135 and 150 DAP respectively (Table 15).

4.1.2.1.5 Photosynthetic water use efficiency

Treatment N_{90} gave maximum value for photosynthetic water use efficiency. However at 105 DAP, its effect was equal to that of N_{120}. The effect of control (N_0)

Table 14. Effect of nitrogen on chlorophyll content and chlorophyll harvest of *Mentha arvensis* L. at five growth stages.

Treatments (kg N/ha)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
	Chlorophyll content (mg g^{-1} fresh weight)				
N_0	1.10	1.21	1.61	2.11	1.94
N_{30}	1.21	1.30	1.80	2.23	2.10
N_{60}	1.28	1.50	1.97	2.35	2.31
N_{90}	1.29	1.75	2.14	2.60	2.51
N_{120}	1.23	1.64	2.06	2.56	2.44
C.D. at 5%	0.03	0.05	0.07	0.03	0.05
	Chlorophyll harvest (mg . cm^2)				
N_0	452.25	3338.79	4764.46	11341.25	9697.57
N_{30}	609.79	4572.09	5781.87	12856.55	14420.47
N_{60}	714.73	6136.95	7099.70	14941.06	14251.73
N_{90}	1000.19	8637.36	8485.76	18453.21	17734.23
N_{120}	901.45	7806.42	8076.50	17886.72	16496.86
C.D. at 5%	80.41	131.92	122.14	170.54	159.14

was lowest at all samplings. Treatment N_{90} increased photosynthetic water use efficiency by 15.44, 15.57, 13.48, 10.63 and 12.55 per cent over the control at 90, 105, 120, 135 and 150 DAP respectively (Table 15).

4.1.2.2 Nutrient contents in plant

For nutrient contents, only nitrogen content was affected significantly by nitrogen application at all stages (Table 16).

4.1.2.2.1 Nitrogen content

Among treatments of nitrogen, N_{90} and control (N_0) gave significant maximum and minimum value respectively at all stages, however at 135 DAP, maximum value registered for N_{90} was equalled by that for N_{120}. The per cent increase in nitrogen content due to N_{90} over the control was 28.93, 35.0, 40.65, 61.69 and 84.24 at 90, 105, 120, 135 and 150 DAP respectively (Table 16).

4.1.2.2.2 Phosphorus content

Phosphorus content was not affected by the application of nitrogen (Table 16).

4.1.2.2.3 Potassium content

For this characteristic also, the effect of nitrogen was found to be non-significant (Table 16).

4.1.2.3 Nutrient uptake

Effect of nitrogen on nutrient uptake at all stages was significant (Table 17).

4.1.2.3.1 Nitrogen uptake

Maximum and minimum value was recorded for N_{90} and the control (N_0) respectively. Application of treatment N_{90} resulted in 84.85, 90.07, 79.17, 108.99 and 136.21 per cent more nitrogen uptake than the control at 90, 105, 120, 135 and 150 DAP respectively (Table 17).

4.1.2.3.2 Phosphorus uptake

Significant maximum value was recorded with N_{90} at all stages and the values was equalled by those for N_{120} at 105 and 120 DAP. The minimum value was recorded with the control (N_0) at all samplings. The per cent increase in phosphorus uptake due to N_{90} over the control was 44.54, 39.63, 28.84, 36.63 and 29.87 at 90, 105, 120, 135 and 150 DAP respectively (Table 17).

Table 15. Effect of nitrogen on photosynthetic rate, stomatal conductance and photosynthetic water use efficiency of *Mentha arvensis* L. at five growth stages

Treatments (kg N/ha)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Photosynthetic rate (μ mol CO_2 $m^{-2}s^{-1}$)		
N_0	9.16	12.36	18.19	24.24	22.98
N_{30}	9.70	13.43	19.88	25.46	24.27
N_{60}	10.98	14.90	20.97	26.94	26.10
N_{90}	11.44	16.27	22.57	29.13	28.22
N_{120}	10.89	16.07	21.65	28.27	27.20
C.D. at 5%	0.38	0.55	0.61	0.56	0.51
			Stomatal conductance (mol $m^{-2}s^{-1}$)		
N_0	0.232	0.258	0.301	0.336	0.330
N_{30}	0.238	0.268	0.309	0.341	0.335
N_{60}	0.248	0.283	0.317	0.350	0.347
N_{90}	0.256	0.294	0.329	0.365	0.360
N_{120}	0.253	0.292	0.322	0.361	0.355
C.D. at 5%	0.006	0.005	0.006	0.006	0.006
			Photosynthetic water use efficiency (μ mol mol^{-1})		
N_0	39.50	47.90	60.44	72.15	69.65
N_{30}	41.37	50.13	64.35	74.67	72.46
N_{60}	44.80	52.67	66.17	76.98	75.21
N_{90}	45.60	55.36	68.59	79.82	78.39
N_{120}	44.65	55.05	67.25	78.83	76.62
C.D. at 5%	0.17	0.68	0.68	0.57	0.74

Table 16. Effect of nitrogen on nitrogen, phosphorus and potassium content of *Mentha arvensis* L. at five growth stages

Treatments (kg N/ha)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Nitrogen (%)		
N_0	3.18	2.80	2.46	2.01	1.65
N_{30}	3.39	3.15	3.01	2.46	1.98
N_{60}	3.59	3.40	3.21	2.86	2.36
N_{90}	4.10	3.78	3.46	3.25	3.04
N_{120}	3.86	3.56	3.32	3.16	2.81
C.D. at 5%	0.18	0.13	0.11	0.21	0.16
			Phosphorus (%)		
N_0	0.313	0.259	0.224	0.200	0.168
N_{30}	0.295	0.261	0.216	0.204	0.172
N_{60}	0.309	0.248	0.224	0.216	0.166
N_{90}	0.315	0.256	0.227	0.211	0.170
N_{120}	0.306	0.262	0.227	0.207	0.158
C.D. at 5%	NS	NS	NS	NS	NS
			Potassium (%)		
N_0	2.92	2.68	2.32	2.01	1.68
N_{30}	2.78	2.56	2.36	1.86	1.70
N_{60}	2.86	2.47	2.30	1.99	1.65
N_{90}	2.90	2.70	2.41	1.98	1.71
N_{120}	2.76	2.66	2.35	2.05	1.64
C.D. at 5%	NS	NS	NS	NS	NS

4.1.2.3.3 Potassium uptake

Maximum value was given by N_{90} at all stages and the value was equalled by that for N_{120} at 105, 120 and 135 DAP. On the other hand, minimum value was recorded for the control (N_0) at all stages.

Application of N_{90} resulted in 41.76, 42.22, 31.99, 27.51 and 30.72 per cent higher potassium uptake than the control at 90, 105, 120, 135 and 150 DAP respectively (Table 17).

4.1.3 Yield characteristics

The effect of nitrogen application on yield characteristics at all stages was significant (Tables 18-20).

4.1.3.1 Leaf number per plant

Significant maximum value was recorded for N_{90} at 135 and 150 DAP but its value was equal to those for N_{120} at 90, 105 and 120 DAP. On the other hand, lowest value was recorded for the control (N_0) at all stages. The per cent increase in leaf number due to N_{90} over the control was 62.72, 75.00, 16.23, 24.41 and 20.59 at 90, 105, 120, 135 and 150 DAP respectively (Table 18).

4.1.3.2 Branch number per plant

Treatment N_{90} at par with N_{120} gave maximum value at all samplings except at 150 DAP, at which maximum value given by N_{90} differed significantly from the values for other treatments. Minimum value was recorded for the control (N_0) at all stages. Treatment N_{90} gave 38.57, 55.96, 31.19, 35.78, 36.79 per cent higher value than the control at 90, 105, 120, 135 and 150 DAP respectively (Table 18).

4.1.3.3 Leaf yield per plant

All nitrogen treatments gave significantly higher value than the control (N_0). Treatment N_{90} proved best at all stages. The minimum value was given by the control. The increase in leaf fresh matter due to N_{90} over the control was 45.62, 46.04, 34.98, 25.86 and 29.84 per cent at 90, 105, 120, 135 and 150 DAP respectively (Table 19).

4.1.3.4 Stem yield per plant

Treatment N_{90} gave maximum and the control (N_0) gave minimum value at all samplings. Application of N_{90} gave 39.28, 45.65, 19.18, 34.00 and 26.49 per cent

Table 17. Effect of nitrogen on nitrogen, phosphorus and potassium uptake of *Mentha arvensis* L. at five growth stages

Treatments (kg N/ha)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Nitrogen (mg plant^{-1})		
N_0	99	141	288	378	301
N_{30}	125	180	383	491	389
N_{60}	145	214	443	604	491
N_{90}	183	268	516	790	711
N_{120}	156	245	485	744	644
C.D. at 5%	12	18	15	21	19
			Phosphorus (mg plant^{-1})		
N_0	9.70	13.02	26.25	37.58	30.63
N_{30}	10.92	14.88	27.48	40.74	33.75
N_{60}	12.48	15.62	30.89	45.58	34.53
N_{90}	14.02	18.18	33.82	51.32	39.78
N_{120}	12.33	18.00	33.16	48.75	36.18
C.D. at 5%	1.01	0.93	0.86	1.12	0.72
			Potassium uptake (mg plant^{-1})		
N_0	91	135	272	378	306
N_{30}	103	146	300	371	333
N_{60}	116	156	317	420	343
N_{90}	129	192	359	482	400
N_{120}	111	183	343	473	376
C.D. at 5%	6	12	16	13	21

Table 18. Effect of nitrogen on leaf and branch number of *Mentha arvensis* L. at five growth stages

Treatments (kg N/ha)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Leaf number plant^{-1}		
N_0	36.67	66.67	203.33	358.33	340.00
N_{30}	44.00	93.33	208.00	373.33	357.33
N_{60}	48.33	104.00	217.67	395.00	383.00
N_{90}	59.67	116.67	236.33	423.00	410.33
N_{120}	55.00	113.33	233.67	410.33	400.00
C.D. at 5%	5.99	4.51	5.03	4.94	6.80
			Branch number plant^{-1}		
N_0	4.33	11.33	20.33	36.33	35.33
N_{30}	4.67	14.67	22.33	39.67	37.67
N_{60}	5.00	16.33	24.33	43.67	42.00
N_{90}	6.00	17.67	26.67	49.33	48.33
N_{120}	5.33	17.00	26.33	47.33	46.33
C.D. at 5%	1.17	1.19	0.87	3.06	1.42

higher value for stem yield than the control at 90, 105, 120, 135 and 150 DAP (Table 19).

4.1.3.5 Herb yield per plant

Application of N_{90} proved best at all stages. Minimum value was recorded for the control (N_0) at all samplings. Treatment N_{90} gave 42.52, 45.88, 22.52, 29.46 and 28.31 per cent more herb yield than the control at 90, 105, 120, 135 and 150 DAP respectively (Table 19).

4.1.3.6 Oil content

Like most of other characteristics, treatment N_{90} gave maximum value for oil content at all stages, however at 120, 135 and 150 DAP its effect was equal to that of N_{120} and at 90 and 105 DAP also to that of N_{60}. The control (N_0) and N_{30} being at par gave minimum value at all stages but at 90 DAP, the control gave significantly minimum value. Treatment N_{90} gave 22.72, 11.76, 24.52, 37.65 and 53.33 per cent more oil content than the control at 90, 105, 120, 135 and 150 DAP respectively (Table 20).

4.1.3.7 Oil yield per plant

Treatment N_{90} gave significantly highest value at 90, 105, 135 and 150 DAP but at 120 DAP, its effect was equal with that of N_{120} and N_{60}. On the other hand, lowest value was noted for the control (N_0) at all stages, however it was and equal by that for N_{30} at 120 DAP. The per cent increase in oil yield due to N_{90} over the control was 74.85, 65.98, 64.17, 73.91 and 99.08 at 90, 105, 120, 135 and 150 DAP respectively (Table 20).

4.2 Experiment 2

This experiment was conducted to select the best phosphorus treatment among various applied phosphorus treatments, viz., 0, 10, 20 30, 40 kg P/ha for performance of the crop. The details of results are given below and summarized in Tables 21-32.

4.2.1. Growth characteristics

The effect of phosphorus application was significantly on all growth parameters at all stages was significant, except specific leaf area at 135 DAP and specific leaf weight at 120 DAP (Tables 21-25).

Table 19. Effect of nitrogen on leaf, stem and herb yield per plant of *Mentha arvensis* L. at five growth stages

Treatments (kg N/ha)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Leaf yield (g plant^{-1})		
N_0	7.30	13.40	26.67	44.23	42.26
N_{30}	8.70	15.17	28.67	46.27	44.83
N_{60}	9.60	17.27	32.90	49.97	48.83
N_{90}	10.63	19.57	36.00	55.67	54.87
N_{120}	8.90	19.13	35.17	55.07	54.10
C.D. at 5%	0.81	0.70	0.92	0.79	0.85
			Stem yield (g plant^{-1})		
N_0	7.00	9.20	26.07	40.00	39.63
N_{30}	8.00	10.52	28.27	43.40	43.35
N_{60}	8.57	11.10	29.17	44.70	44.65
N_{90}	9.75	13.40	31.07	53.60	50.13
N_{120}	9.25	13.10	30.63	50.70	48.70
C.D. at 5%	0.21	0.28	0.14	0.24	0.27
			Herb yield (g plant^{-1})		
N_0	14.30	22.60	54.74	84.54	82.07
N_{30}	16.70	25.69	56.94	89.89	88.31
N_{60}	18.17	28.37	62.07	94.98	93.66
N_{90}	20.38	32.97	67.07	109.45	105.31
N_{120}	18.15	32.23	65.80	105.95	103.07
C.D. at 5%	0.94	1.02	0.80	0.99	1.01

Table 20. Effect of nitrogen on oil content and oil yield of *Mentha arvensis* L. at five growth stages

Treatments (kg N/ha)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Oil content (%) (w/w)		
N_0	0.44	0.51	0.54	0.85	0.75
N_{30}	0.48	0.50	0.53	0.86	0.77
N_{60}	0.52	0.55	0.61	1.00	0.88
N_{90}	0.54	0.57	0.66	1.07	0.95
N_{120}	0.52	0.55	0.65	1.05	0.92
C.D. at 5%	0.02	0.04	0.02	0.02	0.02
			Oil yield (g plant^{-1})		
N_0	3.30	5.56	14.40	37.45	31.69
N_{30}	4.14	7.53	15.35	39.63	34.52
N_{60}	4.99	9.49	19.96	50.13	42.97
N_{90}	5.77	11.22	23.64	69.57	52.17
N_{120}	4.45	10.46	22.74	57.82	49.77
C.D. at 5%	0.43	0.56	3.95	1.01	0.53

4.2.1.1. Plant height

Treatment P_{30} gave maximum value at 120, 135 and 150 DAP and P_{40}, at 90 and 105 DAP, however both treatments were equally effective at 90, 105 and 150 DAP. On the other hand, minimum value was recorded for the control (P_0) at all samplings. The per cent increase in plant height due to P_{30} over the control was 17.19, 21.84, 40.91, 17.84 and 18.91 at 90, 105, 120, 135 and 150 DAP respectively (Table 21).

4.2.1.2 Root length

Maximum value was recorded with P_{30} and was statistically equal to those for P_{40} at 90 and 150 DAP, while at 120, 135 and 150 DAP, each treatment had significant effect. Significant minimum value was recorded for the control (P_0) at all samplings. Treatment P_{30} increased root length by 46.17, 39.30, 38.79, 41.28 and 34.79 per cent compared with the control at 90, 105, 120, 135 and 150 DAP respectively (Table 21).

4.2.1.3 Leaf area per plant

For leaf area also, application of P_{30} proved best at all stages. Significantly lowest value was noted for the control (P_0) at all samplings except at 120 DAP, at which lowest value recorded for P_{10} was equalled by that for the control. The per cent increase in leaf area resulted from application of P_{30} was 55.58, 91.79, 25.74, 13.92 and 16.23 over the control at 90, 105, 120, 135 and 150 DAP respectively (Table 22).

4.2.1.4 Leaf area ratio

Treatment P_{30} gave maximum value at 90, 105 and 120 DAP, however the control registered highest value at 135 DAP and treatment P_{10}, at 150 DAP. The increase in leaf area ratio due to P_{30} over the control was 10.66, 38.35 and 9.98 at 90, 105 and 120 DAP respectively (Table 22).

4.2.1.5 Specific leaf area

Specific leaf area was affected by application of phosphorus significantly at all stages except at 135 DAP. Treatment P_{30} proved best at 90, 105, 120 and 150 DAP, however its effect was at par with that of P_{20} at 105 DAP. The per cent increase in specific leaf area due to P_{30} over the control was 24.43, 51.96, 8.77 and 5.56 at 90, 105, 120 and 150 DAP respectively (Table 22).

Table 21. Effect of phosphorus on plant height and root length of *Mentha arvensis* L. at five growth stages

Treatments (kg P/ha)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Plant height (cm)		
P_0	31.00	39.50	44.83	57.00	56.62
P_{10}	33.00	43.50	47.00	61.83	62.00
P_{20}	34.17	45.00	52.17	64.00	64.17
P_{30}	36.33	48.13	63.17	67.17	67.33
P_{40}	36.50	48.27	54.50	65.83	66.00
C.D. at 5%	1.73	0.73	1.77	1.16	1.33
			Root length (cm)		
P_0	10.83	12.80	17.17	21.00	19.17
P_{10}	13.17	14.47	19.17	23.66	21.67
P_{20}	13.83	15.50	20.50	26.33	25.17
P_{30}	15.83	17.83	23.83	29.67	28.67
P_{40}	15.33	17.17	22.50	28.00	26.83
C.D. at 5%	0.93	0.94	0.69	1.60	1.32

Table 22. Effect of phosphorus on leaf area, leaf area ratio and specific leaf area of *Mentha arvensis* L. at five growth stages.

Treatments (kg P/ha)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Leaf area (cm^2 $plant^{-1}$)		
P_0	403	901	2871	5468	5137
P_{10}	502	1244	2832	5555	5452
P_{20}	540	1480	3058	5734	5597
P_{30}	642	1728	3610	6229	5971
P_{40}	627	1662	3505	6069	5724
C.D. at 5%	23.00	28.00	32.00	35.00	37.00
			Leaf area ratio (cm^2g^{-1})		
P_0	281.82	478.52	500.63	599.94	568.93
P_{10}	283.61	608.53	460.53	596.68	577.57
P_{20}	297.86	621.85	490.07	556.55	561.36
P_{30}	311.85	662.04	550.59	531.36	529.85
P_{40}	307.24	656.92	537.58	525.73	508.82
C.D. at 5%	10.39	15.02	25.18	10.44	21.79
			Specific leaf area (cm^2 g^{-1})		
P_0	256.69	289.91	471.43	500.18	482.80
P_{10}	267.02	380.73	481.96	565.14	492.94
P_{20}	282.72	432.76	472.00	477.04	490.53
P_{30}	319.40	440.56	512.78	516.68	509.64
P_{40}	313.50	433.98	506.50	501.22	495.58
C.D. at 5%	36.21	24.51	23.74	NS	11.54

4.2.1.6 Leaf dry weight

Phosphorus at P_{30} proved best for leaf dry weight at all stages. On the other hand control (P_0) showed lowest effect at all stages except at 120 DAP, at which P_{10} gave minimum value. The per cent increase in leaf dry weight due to P_{30} over the control was 28.02 at 90 DAP, 26.04 at 105 DAP, 19.73 at 120 DAP, 10.80 at 135 DAP and 10.15 at 150 DAP (Table 23).

4.2.1.7 Specific leaf weight

Effect of phosphorus on specific leaf weight was significant at all stages, except 120 DAP. Increasing doses of phosphorus decreased specific leaf weight. The per cent decrease in specific leaf weight due to P_{30} in comparison with the control (P_0) was 24.60, 51.98, 3.63 and 5.61 at 90, 105, 135 and 150 DAP respectively (Table 23).

4.2.1.8 Stem dry weight

Application of P_{30} proved best for stem dry weight at all stages. The control (P_0) gave significant lowest value at all stages. Treatment P_{30} increased stem dry weight by 54.88, 38.83, 14.29, 28.51 and 24.81 per cent over the control at 90, 105, 120, 135 and 150 DAP respectively (Table 24).

4.2.1.9 Aboveground plant dry weight

Treatment P_{30} gave maximum value at all stages, however its effect was at par with those of P_{40} at 90, 120 and 135 DAP. Treatment P_{30} increased aboveground plant dry weight by 46.40, 34.60, 14.96, 19.00 and 16.92 per cent over the control at 90, 105, 120, 135 and 150 DAP respectively (Table 24).

4.2.1.10 Under ground plant fresh weight

Treatment P_{30} proved best at all stages. Minimum value was noted for the control (P_0) at all samplings. Treatment P_{30} gave 73.25, 57.60, 47.98, 50.87 and 51.89 per cent higher value for underground plant fresh weight than the control at 90, 105, 120, 135 and 150 DAP respectively (Table 25).

4.2.1.11 Underground plant dry weight

Phosphorus at P_{30} proved best for underground plant dry weight at all stages. The control (P_0) gave significant lowest value at all stages of sampling. Application of P_{30} gave 73.03, 57.63, 48.44, 50.84 and 52.12 per cent higher value for underground

Table 23. Effect of phosphorus on leaf dry weight per plant and specific leaf weight of *Mentha arvensis* L. at five growth stages.

Treatments (kg P/ha)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Leaf dry weight (g plant^{-1})		
P_0	1.57	3.11	6.09	10.93	10.64
P_{10}	1.88	3.27	5.88	11.26	11.06
P_{20}	1.91	3.42	6.44	12.02	11.41
P_{30}	2.01	3.92	7.04	12.11	11.72
P_{40}	2.00	3.83	6.92	12.06	11.55
C.D. at 5%	0.04	0.19	0.15	0.32	0.22
			Specific leaf weight (mg cm^{-2})		
P_0	3.90	3.45	2.12	2.00	2.07
P_{10}	3.75	2.63	2.08	2.03	2.03
P_{20}	3.54	2.31	2.12	2.09	2.04
P_{30}	3.13	2.27	1.95	1.93	1.96
P_{40}	3.19	2.30	1.97	1.99	2.02
C.D. at 5%	0.06	0.13	NS	0.09	0.07

Table 24. Effect of phosphorus on stem dry weight and aboveground dry weight of *Mentha arvensis* L. at five growth stages

Treatments (kg P/ha)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Stem dry weight (g plant^{-1})		
P_0	1.43	1.88	5.74	9.12	9.03
P_{10}	1.77	2.04	6.15	9.61	9.44
P_{20}	1.81	2.38	6.24	10.30	9.97
P_{30}	2.06	2.61	6.56	11.72	11.27
P_{40}	2.04	2.53	6.52	11.57	11.25
C.D. at 5%	0.06	0.04	0.10	0.17	1.33
			Aboveground plant dry weight (g plant^{-1})		
P_0	3.00	5.00	11.83	20.05	19.67
P_{10}	3.65	5.31	12.03	20.90	20.50
P_{20}	3.73	5.80	12.70	22.36	21.42
P_{30}	4.07	6.73	13.60	23.86	23.00
P_{40}	4.04	6.36	13.44	23.69	22.82
C.D. at 5%	0.05	0.18	0.28	0.37	0.17

plant dry weight than the control at 90, 105, 120, 135 and 150 DAP, respectively (Table 25).

4.2.2 Physiological characteristics

4.2.2.1 Photosynthetic characteristics

All the photosynthetic characteristics at all stages were affected significantly by phosphorus application (Tables 26-27).

4.2.2.1.1 Chlorophyll content

Treatment P_{30} gave maximum value at 90, 105 and 150 DAP, but at 135 DAP its maximum value was equalled by that for P_{40}. At 120 DAP, maximum value for P_{40} was equalled by that for P_{30}. ~~Significant~~ The lowest value was given by the control (P_0) at 90, 105 and 150 DAP but at 120 and 135 DAP, its minimum value was equalled by that for P_{10}. Treatment P_{30} gave 16.38, 19.00, 22.15, 20.10 and 32.57 per cent increase in chlorophyll content over the control at 90, 105, 120, 135 and 150 DAP, respectively (Table 26).

4.2.2.1.2 Chlorophyll harvest

Application of P_{30} proved best for chlorophyll harvest at all stages. The value recorded for the control (P_0) was lowest and the difference was significant from other treatments at 90, 105, 135 and 150 DAP at 120 DAP, while its effect was at par with that of P_{10}. Treatment P_{30} gave 89.46, 136.84, 51.19, 36.82 and 54.09 per cent increase in chlorophyll harvest over the control at 90, 105, 120, 135 and 150 DAP, respectively (Table 26).

4.2.2.1.3 Photosynthetic rate

Maximum value was recorded for P_{30} at all the growth stages. On the other hand, ~~significant~~ the lowest value was recorded for the control (P_0). The per cent increase in rate of photosynthesis was 24.94, 27.48, 33.54, 28.14, 26.90 due to P_{30} over the control at 90, 105, 120, 135 and 150 DAP, respectively (Table 27).

4.2.2.1.4 Stomatal conductance

Treatment P_{30} gave maximum value at all stages of sampling, however at 105 and 120 DAP, P_{30} and P_{40} were equally effective. Minimum value was recorded for the control (P_0) at all stages. The increase in stomatal conductance due to P_{30} over the

Table 25. Effect of phosphorus on underground plant fresh weight and dry weight of *Mentha arvensis* L. at five growth stages

Treatments (kg P/ha)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Underground plant fresh weight (g plant^{-1})		
P_0	4.00	5.33	10.17	16.12	15.90
P_{10}	4.87	6.22	12.07	18.53	18.35
P_{20}	5.57	7.40	13.60	20.68	20.50
P_{30}	6.93	8.40	15.05	24.32	24.15
P_{40}	6.50	8.28	14.87	24.15	23.97
C.D. at 5%	0.38	0.30	0.17	0.18	0.21
			Underground plant dry weight (g plant^{-1})		
P_0	0.89	1.18	2.25	3.58	3.53
P_{10}	1.15	1.37	2.68	4.12	4.08
P_{20}	1.23	1.64	3.02	4.59	4.55
P_{30}	1.54	1.86	3.34	5.40	5.37
P_{40}	1.44	1.84	3.30	5.36	5.32
C.D. at 5%	0.04	0.07	0.11	0.04	0.05

Table 26. Effect of phosphorus on chlorophyll content and chlorophyll harvest of *Mentha arvensis* L. at five growth stages

Treatments (kg P/ha)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
	Chlorophyll content (mg g^{-1} fresh weight)				
P_0	1.16	1.21	1.58	2.09	1.75
P_{10}	1.21	1.33	1.60	2.13	1.89
P_{20}	1.25	1.38	1.71	2.36	2.13
P_{30}	1.35	1.44	1.90	2.51	2.32
P_{40}	1.29	1.41	1.93	2.46	2.23
C.D. at 5%	0.01	0.02	0.07	0.08	0.08
	Chlorophyll harvest (mg . cm^2)				
P_0	467.91	1090.56	4536.78	11427.60	8990.52
P_{10}	607.87	1653.92	4531.65	11832.81	10305.07
P_{20}	675.12	2041.89	5229.49	13533.07	11921.08
P_{30}	886.50	2488.13	6859.09	15635.54	13853.69
P_{40}	808.69	2343.83	6955.72	14930.58	12764.99
C.D. at 5%	53.81	153.85	104.93	183.79	131.68

control was 7.66, 11.06, 15.17, 11.22 and 10.65 per cent at 90, 105, 120, 135 and 150 DAP respectively (Table 27).

4.2.2.1.5 Photosynthetic water use efficiency

Treatment P_{30} registered maximum value at all samplings, however the effect of P_{30} and P_{40} was equal to each other at 120, 135 and 150 DAP but the maximum value for P_{30} significantly differed from other treatments at 90 and 105 DAP. On the other hand, lowest value was given by the control (P_0) at all stages. The per cent increase in photosynthetic water use efficiency resulted from the application of P_{30} over the control was 19.73, 13.28, 15.94, 15.18 and 15.41 at 90, 105, 120, 135 and 150 DAP respectively (Table 27).

4.2.2.2 Nutrient contents in plant

Application of phosphorus affected phosphorus content only at all stages significantly (Table 28).

4.2.2.2.1 Nitrogen content

Nitrogen content remained unaffected by the application of phosphorus at all samplings (Table 28).

4.2.2.2.2 Phosphorus content

Significant maximum and minimum value was recorded for P_{30} and the control (P_0) respectively at all stages except at 150 DAP at which maximum value for P_{30} was equalled by that for P_{40}. The increase in phosphorus content due to P_{30} over the control was 38.15, 29.35, 83.33, 30.14 and 18.97 per cent at 90, 105, 120, 135 and 150 DAP respectively (Table 28).

4.2.2.2.3 Potassium content

Data recorded for potassium concentration was found to be non significant at all samplings (Table 28).

4.2.2.3 Nutrient uptake

Effect of phosphorus on nutrient uptake at all stages was significant (Table 29).

4.2.2.3.1 Nitrogen uptake

Treatment P_{30} gave maximum value at all growth stages, except at 90 DAP at which, its value was equalled by that for P_{40}. Treatment P_{30} gave 67.37, 28.77, 33.58,

Table 27. Effect of phosphorus on photosynthetic rate, stomatal conductance and photosynthetic water use efficiency of *Mentha arvensis* L. at five growth stages

Treatments (kg P/ha)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Photosynthetic rate (μ mol CO_2 $m^{-2}s^{-1}$)		
P_0	8.74	11.61	14.34	20.72	20.11
P_{10}	9.25	12.55	15.50	22.09	21.55
P_{20}	10.22	13.70	17.13	24.73	23.30
P_{30}	10.92	14.80	19.15	26.55	25.52
P_{40}	10.59	14.49	18.81	26.19	25.11
C.D. at 5%	0.11	0.15	0.29	0.18	0.19
			Stomatal conductance (mol m^{-2} s^{-1})		
P_0	0.222	0.244	0.257	0.294	0.291
P_{10}	0.230	0.251	0.270	0.301	0.296
P_{20}	0.235	0.263	0.285	0.315	0.309
P_{30}	0.239	0.271	0.296	0.327	0.322
P_{40}	0.236	0.269	0.293	0.324	0.318
C.D. at 5%	0.002	0.006	0.003	0.001	0.002
			Photosynthetic water use efficiency (μ mol mol^{-1})		
P_0	38.17	48.20	55.80	70.50	69.10
P_{10}	40.20	50.00	57.40	73.40	72.80
P_{20}	43.50	52.10	60.10	78.50	75.40
P_{30}	45.70	54.60	64.70	81.20	79.75
P_{40}	44.90	53.90	64.20	80.85	78.95
C.D. at 5%	0.77	0.19	0.59	0.63	1.16

Table 28. Effect of phosphorus on nitrogen, phosphorus and potassium content of *Mentha arvensis* L. at five growth stages

Treatments (kg P/ha)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Nitrogen (%)		
P_0	3.20	2.70	2.30	2.01	1.72
P_{10}	3.19	2.85	2.10	1.98	1.75
P_{20}	3.04	2.75	2.30	2.05	1.71
P_{30}	3.25	2.67	2.35	2.09	1.73
P_{40}	3.18	2.50	2.23	2.04	1.68
C.D. at 5%	NS	NS	NS	NS	NS
			Phosphorus (%)		
P_0	0.346	0.310	0.240	0.209	0.170
P_{10}	0.408	0.328	0.304	0.230	0.195
P_{20}	0.429	0.359	0.336	0.246	0.215
P_{30}	0.478	0.401	0.374	0.272	0.232
P_{40}	0.453	0.385	0.359	0.258	0.223
C.D. at 5%	0.19	0.09	0.13	0.12	0.14
			Potassium (%)		
P_0	2.85	2.50	2.30	1.90	1.64
P_{10}	2.95	2.52	2.41	1.78	1.72
P_{20}	2.78	2.68	2.26	1.95	1.60
P_{30}	2.85	2.55	2.32	1.91	1.78
P_{40}	2.70	2.53	2.15	1.86	1.55
C.D. at 5%	NS	NS	NS	NS	NS

35.59 and 25.29 per cent higher value for nitrogen uptake than the control (P_0) at 90, 105, 120, 135 and 150 DAP respectively (Table 29).

4.2.2.3.2 Phosphorus uptake

Among applied treatments of phosphorus, P_{30} gave significant maximum value at 105, 120, 135 and 150 DAP but at 90 DAP it was equal in effect with P_{40}. On the other hand control (P_0) showed significantly lowest effect at all stages. The increase in phosphorus uptake due to P_{30} over the control was 127.83, 68.34, 41.71, 65.89 and 70.26 per cent at 90, 105, 120, 135 and 150 DAP respectively (Table 29).

4.2.2.3.3 Potassium uptake

Maximum value was recorded for P_{30} and its effect showed significant difference from those of other treatments at 120 and 150 DAP but at 90, 105 and 135 DAP, effect of P_{30} was at par with that of P_{40}. Significant minimum value was recorded with the control at 90, 120, 135 and 150 DAP but at 105 DAP, it was at par with that for P_{10}. The increase in potassium uptake due to P_{30} over the control was 65.48, 33.33, 26.15, 28.16 and 35.43 per cent at 90, 105, 120, 135 and 150 DAP respectively (Table 29).

4.2.3 Yield characteristics

All yield parameters at all stages were affected significantly by phosphorus application (Tables 30-32).

4.2.3.1 Leaf number per plant

Application of P_{30} proved best for leaf number per plant at all stages. The control (P_0) gave lowest value at all stages except at 120 DAP, at which P_{10} gave minimum value. Treatment P_{30} gave 49.99, 83.66, 22.37, 12.90 and 14.88 per cent higher leaf number over the control at 90, 105, 120, 135 and 150 DAP respectively (Table 30).

4.2.3.2 Branch number per plant

Treatment P_{30} gave maximum value at all stages, however it was equal in effect with P_{40} at 90, 105 and 150 DAP. The control (P_0) gave lowest value at all stages, however its value was at par with those for P_{10} and P_{20} at 90 DAP and with that for P_{10} at 105 DAP. The per cent increase in branch number due to P_{30} over the

Table 29. Effect of phosphorus on nitrogen, phosphorus and potassium uptake of *Mentha arvensis* L. at five growth stages.

Treatments (kg P/ha)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Nitrogen (mg plant^{-1})		
P_0	95	146	283	402	340
P_{10}	111	159	271	409	357
P_{20}	121	165	314	468	377
P_{30}	159	188	362	533	426
P_{40}	153	171	339	517	410
C.D. at 5%	9.00	10.00	8.00	12.00	9.00
			Phosphorus (mg plant^{-1})		
P_0	10.24	16.77	29.54	41.78	33.56
P_{10}	14.24	18.24	39.19	47.50	39.74
P_{20}	17.12	21.54	45.83	56.19	47.41
P_{30}	23.33	28.23	41.86	69.31	57.14
P_{40}	21.74	26.26	39.27	65.43	54.48
C.D. at 5%	1.68	0.92	1.36	2.00	1.46
			Potassium (mg plant^{-1})		
P_0	84	135	283	380	324
P_{10}	103	140	311	368	351
P_{20}	111	161	308	445	353
P_{30}	139	180	357	487	439
P_{40}	130	173	327	472	379
C.D. at 5%	12.00	17.00	11.00	15.00	14.00

control was 71.54, 33.33, 61.00, 59.79 and 57.75 at 90, 105, 120, 135 and 150 DAP respectively (Table 30).

4.2.3.3 Leaf yield per plant

Treatment P_{30} gave maximum value at all stages but was equal in effect with P_{40} at 105, 120 and 135 DAP, however at 90 and 150 DAP the effect of each treatment was significant. The control gave minimum value but its minimum value was equal with that of P_{10} at 120 DAP and at 105 DAP also with that of P_{20}. Treatment P_{30} gave 28.00, 32.14, 15.58, 10.79 and 10.13 per cent more leaf fresh matter than the control at 90, 105, 120, 135 and 150 DAP respectively (Table 31).

4.2.3.4 Stem yield per plant

Treatment P_{30} gave maximum value at all stages, but its effect was at par with that of P_{40} at 90, 120 and 150 DAP. The per cent increase in stem yield due to P_{30} over the control was 54.50, 38.47, 14.11, 28.61 and 24.78 at 90, 105, 120, 135 and 150 DAP respectively (Table 31).

4.2.3.5 Herb yield per plant

Among applied treatments, P_{30} gave maximum herb yield per plant at all stages, however P_{30} and P_{40} were equally effective at 120 and 135 DAP. On the other hand, ~~significant~~ the lowest value for this parameter was recorded for P_0 at all samplings. P_{30} increased herb yield over the control by 64.00, 66.32, 25.22, 27.19 and 24.85 per-cent at 90, 105, 120, 135 and 150 DAP respectively (Table 31).

4.2.3.6 Oil content

Treatment P_{30} proved best for oil content. Its effect was equalled by those of P_{40} at 105, 120, 135 and 150 DAP and also by that of P_{20} at 90 DAP. The control (P_0) gave the lowest value and its effect was at par with those of P_{10} at 90, 105, 120 and 150 DAP. Treatment P_{30} gave 18.60, 20.00, 19.64, 31.25 and 33.33 per cent higher oil content than the control at 90, 105, 120, 135 and 150 DAP respectively (Table 32).

4.2.3.7 Oil yield per plant

Among applied treatments of phosphorus, P_{30} gave maximum value at all stages, however at 90 DAP, its effect was equalled by that of P_{40}. The control (P_0) gave the lowest value at all sampling stages, except 90 DAP, at which its effect was equalled by that of P_{10}. The per cent increase in oil yield resulted from the application

Table 30. Effect of phosphorus on leaf and branch number of *Mentha arvensis* L. at five growth stages

Treatments (kg P/ha)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Leaf number plant^{-1}		
P_0	36.67	69.33	196.67	356.67	336.00
P_{10}	45.67	95.00	193.33	363.33	355.67
P_{20}	47.67	111.00	207.33	373.33	367.00
P_{30}	55.00	127.33	240.67	402.67	386.00
P_{40}	55.33	124.33	240.00	392.33	372.67
C.D. at 5%	1.14	3.12	11.83	7.85	7.85
			Branch number plant^{-1}		
P_0	3.69	15.00	20.00	34.00	32.33
P_{10}	4.00	16.33	19.67	36.00	34.67
P_{20}	4.67	17.67	26.00	46.00	45.67
P_{30}	6.33	20.00	31.67	54.33	51.00
P_{40}	6.00	19.00	29.67	49.00	49.00
C.D. at 5%	1.16	1.42	2.92	1.93	2.75

Table 31. Effect of phosphorus on leaf, stem and herb yield of *Mentha arvensis* L. at five growth stages

Treatments (kg P/ha)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Leaf yield (g plant^{-1})		
P_0	7.07	14.00	27.41	49.19	47.88
P_{10}	8.46	14.70	26.43	50.67	49.77
P_{20}	8.60	15.40	29.50	54.09	51.35
P_{30}	9.05	18.50	31.68	54.50	52.73
P_{40}	9.00	17.23	31.14	54.27	52.00
C.D. at 5%	0.20	1.70	0.70	1.05	0.11
			Stem yield (g plant^{-1})		
P_0	6.00	8.50	25.87	41.03	40.63
P_{10}	7.10	9.22	27.70	41.90	42.67
P_{20}	8.18	9.82	28.10	46.37	44.87
P_{30}	9.27	11.77	29.50	52.77	50.70
P_{40}	9.20	11.40	29.37	52.03	50.63
C.D. at 5%	0.23	0.18	0.46	0.16	0.84
			Herb yield (g plant^{-1})		
P_0	12.50	18.20	51.74	84.40	82.90
P_{10}	14.67	23.92	54.13	86.86	85.63
P_{20}	16.78	25.21	57.60	96.05	92.68
P_{30}	20.50	30.27	64.79	107.35	103.50
P_{40}	20.18	28.63	64.10	106.60	102.70
C.D. at 5%	0.25	0.85	0.83	1.59	0.70

of P_{30} was 51.97, 58.57, 38.31, 45.41 and 46.82 over the control at 90, 105, 120, 135 and 150 DAP respectively (Table 32).

4.3 Experiment 3

This experiment was conducted to investigate the effect of foliar spray of GA_3, viz. 0, 10^{-4}, 10^{-3} and 10^{-2}M and water-sprayed control (W_0) on growth, physiological and yield characteristics at various sampling stages as described in Experiments 1, 2 and 3. The details of results (Tables 33-44) are summarized below.

4.3.1 Growth characteristics

Effect of foliar application of GA_3 on growth characteristics at each stage was significant except specific leaf area and specific leaf weight at 150 DAP (Tables 33-37).

4.3.1.1 Plant height

Increasing levels of GA_3 enhanced plant height linearly. The per cent increase in plant height resulted from 10^{-2}M GA_3 was 33.06, 34.06, 42.74, 60.15 and 61.03 per cent and from 10^{-4}M GA_3 was 14.94, 12.65, 22.04, 32.59 and 34.35 per cent over the water-sprayed control (W_0) at 90, 105, 120, 135 and 150 DAP respectively (Table 33).

4.3.1.2 Root length

Treatment 10^{-4}M GA_3 gave significant maximum value at 90, 105, 135 and 150 DAP but at 120 DAP, it was equalled by that for 10^{-3}M GA_3. The effect of water-sprayed control (W_0) was significantly lowest at all samplings. Treatment 10^{-4}M GA_3 increased root length by 25.45, 42.13, 18.11, 21.65 and 21.28 per cent over the control at 90, 105, 120, 135 and 150 DAP respectively (Table 33).

4.3.1.3 Leaf area per plant

Among sprayed treatments, 10^{-4}M GA_3 gave significant maximum value at all stages of sampling except 90 DAP, at which maximum value for 10^{-4}M GA_3 was equalled to that for 10^{-3}M GA_3 and 10^{-2}M GA_3. On the other hand, significant minimum value was recorded for the water-sprayed control (W_0) at all stages. The per-cent increase in leaf area due to 10^{-4}M GA_3 over the water-sprayed control was 14.29, 25.82, 17.44, 6.93 and 18.76 at 90, 105, 120, 135 and 150 DAP respectively (Table 34).

Table 32. Effect of phosphorus on oil content and oil yield of *Mentha arvensis* L. at five growth stages

Treatments (kg P/ha)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Oil content (%) (w/w)		
P_0	0.43	0.50	0.56	0.80	0.69
P_{10}	0.43	0.52	0.56	0.87	0.71
P_{20}	0.49	0.55	0.62	0.93	0.78
P_{30}	0.51	0.60	0.67	1.05	0.92
P_{40}	0.50	0.59	0.65	1.02	0.89
C.D. at 5%	0.03	0.04	0.02	0.06	0.03
			Oil yield (g plant^{-1})		
P_0	3.04	7.00	15.35	39.35	33.04
P_{10}	3.64	7.64	14.80	44.08	35.34
P_{20}	4.21	8.47	18.29	50.30	40.05
P_{30}	4.62	11.10	21.23	57.22	48.51
P_{40}	4.50	10.16	20.24	55.35	46.28
C.D. at 5%	1.02	0.22	0.27	1.41	1.15

Table 33. Effect of leaf-applied gibberellic acid on plant height and root length of *Mentha arvensis* L. at five stages.

Spray concentrations (M)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Plant height (cm)		
GA_3 (0)	31.06	38.17	52.17	66.50	65.00
$GA_3 \times 10^{-4}$	35.17	43.00	63.67	88.17	87.33
$GA_3 \times 10^{-3}$	40.00	47.33	67.50	96.00	94.07
$GA_3 \times 10^{-2}$	41.33	51.17	74.47	106.50	104.67
C.D. at 5%	1.10	0.96	1.50	1.19	1.86
			Root length (cm)		
GA_3 (0)	11.16	15.83	19.33	20.00	19.83
$GA_3 \times 10^{-4}$	14.00	22.50	22.83	24.33	24.05
$GA_3 \times 10^{-3}$	13.17	21.50	21.00	23.17	22.99
$GA_3 \times 10^{-2}$	12.33	19.00	20.17	22.00	21.33
C.D. at 5%	0.70	1.19	0.69	1.07	0.90

4.3.1.4 Leaf area ratio

Maximum value was recorded for the water-sprayed control (W_0) at all stages, except at 90 DAP at which 10^{-2}M GA_3 gave maximum value. Both of the treatments, viz. the water-sprayed control (W_0) and 10^{-2}M GA_3 were equally effective at 90, 105 and 120 DAP and also with 10^{-3}M GA_3 at 150 DAP. On the other hand, significant minimum value was recorded for 10^{-4}M GA_3 at all samplings. The per cent decrease in leaf area ratio due to 10^{-4}M GA_3 in comparison with the water-sprayed control was 30.18, 19.93, 7.99, 18.18 and 9.47 at 90, 105, 120, 135 and 150 DAP, respectively (Table 34).

4.3.1.5 Specific leaf area

A significant maximum value for this characteristic was recorded for the water-sprayed control (W_0) at 90, 105 and 120 DAP but its value was equalled by that for 10^{-3}M GA_3 and 10^{-2}M GA_3 at 135 DAP. On the other hand, significant minimum value was recorded for 10^{-4}M GA_3 at 90, 105, 120 and 135 DAP. The effect at 150 DAP was found to be non-significant. The decrease in specific leaf area due to 10^{-4}M GA_3 in comparison with the water-sprayed control (W_0) was 33.33, 18.29, 15.94 and 6.70 per cent at 90, 105, 120 and 135 DAP, respectively (Table 34).

4.3.1.6 Leaf dry weight

Treatment 10^{-4}M GA_3 gave maximum value for leaf dry weight at all samplings, however at 90 DAP, its effect was equalled by that of 10^{-3}M GA_3. Significant minimum value was registered for water-sprayed control (W_0) at all stages except at 150 DAP, at which its value was equal to 10^{-2}M GA_3 and 10^{-3}M GA_3. The per cent increase in leaf dry weight due to 10^{-4}M GA_3 over the water-sprayed control (W_0) was 53.38, 33.22, 23.12, 14.09 and 17.86 at 90, 105, 120, 135 and 150 DAP, respectively (Table 35).

4.3.1.7 Specific leaf weight

Treatment 10^{-4}M GA_3 gave significant maximum values for specific leaf weight at 90, 105, 120 and 135 DAP. On the other hand, minimum value was recorded for the water-sprayed control (W_0) which was equalled by that for 10^{-2}M GA_3 at 90 DAP by those for 10^{-3}M GA_3 and 10^{-2}M GA_3 at 105, 120 and 135 DAP. The effect at 150 DAP was non-significant. The per cent increase in specific leaf

Table 34. Effect of leaf-applied gibberellic acid on leaf area, leaf area ratio and specific leaf area of *Mentha arvensis* L. at five stages

Spray concentrations (M)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Leaf area (cm^2 $plant^{-1}$)		
GA_3 (0)	560	1247	3160	5452	4493
$GA_3 \times 10^{-4}$	640	1569	3711	5830	5336
$GA_3 \times 10^{-3}$	637	1502	3680	5672	5164
$GA_3 \times 10^{-2}$	636	1404	3597	5580	5136
C.D. at 5%	11	32	20	34	24
			Leaf area ratio (cm^2g^{-1})		
GA_3 (0)	341.46	556.70	576.65	570.89	486.78
$GA_3 \times 10^{-4}$	262.30	464.20	533.96	479.84	444.67
$GA_3 \times 10^{-3}$	312.25	538.47	561.83	516.58	479.04
$GA_3 \times 10^{-2}$	345.65	550.59	566.46	516.67	486.36
C.D. at 5%	16.79	14.15	11.58	12.10	8.47
			Specific leaf area (cm^2g^{-1})		
GA_3 (0)	333.33	487.11	557.32	560.94	480.53
$GA_3 \times 10^{-4}$	250.00	411.81	480.70	525.70	484.21
$GA_3 \times 10^{-3}$	272.22	465.02	545.19	559.37	537.36
$GA_3 \times 10^{-2}$	311.76	469.56	546.66	555.78	536.12
C.D. at 5%	15.66	11.19	8.26	9.25	NS

weight due to 10^{-4}M GA_3 over water-sprayed control at 90, 105, 120 and 135 DAP was 33.33, 18.54, 16.20 and 6.74 per cent respectively (Table 35).

4.3.1.8 Stem dry weight

Among applied treatments of GA_3, the highest significant effect was found for 10^{-4}M GA_3 at all samplings. The effect of water-sprayed control (W_0) was minimum at all stages but at 120 DAP, its lowest effect was equalled by that of 10^{-2}M GA_3. The increase in stem dry weight due to the application of 10^{-4}M GA_3 over the water-sprayed control was 48.78, 50.89, 26.82, 27.22 and 30.01 per cent at 90, 105, 120, 135 and 150 DAP, respectively (Table 36).

4.3.1.9 Aboveground plant dry weight

Maximum value was recorded for 10^{-4}M GA_3, and the difference was significant from the values recorded for other treatments at all samplings. Minimum value was recorded for water-sprayed control (W_0) at all stages, however its effect was equalled by that of 10^{-2}M GA_3 at 105 DAP. The per cent increase in plant dry weight due to 10^{-4}M GA_3 over the water-sprayed control was 55.19, 41.18, 28.93, 20.65 and 22.38 at 90, 105, 120, 135 and 150 DAP, respectively (Table 36).

4.3.1.10 Underground plant fresh weight

Among spray treatments of GA_3, treatment 10^{-4}M GA_3 gave maximum value for underground plant fresh weight, and differed significantly form the values recorded for other treatments at all samplings. On the other hand, lowest values was recorded for 10^{-2}M GA_3 at all stages, except at 90 DAP at which water-sprayed control (W_0) was recorded with lowest value. The per cent increase in underground fresh weight due to 10^{-4}M GA_3 over the water-sprayed control was 47.67, 61.60, 24.72, 22.39 and 21.65 at 90, 105, 120, 135 and 150 DAP, respectively (Table 37).

4.3.1.11 Underground plant dry weight

Treatment 10^{-4}M GA_3 gave significantly maximum values at all samplings. On the other hand, 10^{-2}M GA_3 and the control (W_0) being at par gave minimum values at all stages. They were also at par with 10^{-3}M GA_3 in effect at 90, 120 and 150 DAP. Treatment 10^{-4}M GA_3 gave 46.27, 61.54, 24.58, 22.15 and 21.72 per cent increase in underground plant dry weight compared with the water-sprayed control (W_0) at 90, 105, 120, 135 and 150 DAP, respectively (Table 37).

Table 35. Effect of leaf-applied gibberellic acid on leaf dry weight and specific leaf weight of *Mentha arvensis* L. at five stages

Spray concentrations (M)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Leaf dry weight (g plant^{-1})		
GA_3 (0)	1.68	2.56	5.67	9.72	9.35
$GA_3 \times 10^{-4}$	2.56	3.81	7.72	11.09	11.02
$GA_3 \times 10^{-3}$	2.34	3.23	6.75	10.14	9.61
$GA_3 \times 10^{-2}$	2.04	2.99	6.58	10.04	9.58
C.D. at 5%	0.34	0.19	0.15	0.11	0.63
			Specific leaf weight (mg cm^{-2})		
GA_3 (0)	3.00	2.05	1.79	1.78	2.08
$GA_3 \times 10^{-4}$	4.00	2.43	2.08	1.90	2.07
$GA_3 \times 10^{-3}$	3.67	2.15	1.83	1.78	1.86
$GA_3 \times 10^{-2}$	3.21	2.13	1.83	1.80	1.86
C.D. at 5%	0.22	0.26	0.17	0.06	NS

Table 36. Effect of leaf-applied gibberellic acid on stem dry weight and aboveground plant dry weight of *Mentha arvensis* L. at five stages

Spray concentrations (M)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Stem dry weight (g plant^{-1})		
GA_3 (0)	1.64	2.24	5.48	9.55	9.23
$GA_3 \times 10^{-4}$	2.44	3.38	6.15	12.15	12.00
$GA_3 \times 10^{-3}$	2.04	2.79	6.55	10.98	10.78
$GA_3 \times 10^{-2}$	1.84	2.55	6.35	10.80	10.56
C.D. at 5%	0.08	0.19	0.22	0.21	0.22
			Aboveground plant dry weight (g plant^{-1})		
GA_3 (0)	3.37	4.80	11.75	19.27	18.81
$GA_3 \times 10^{-4}$	5.23	7.20	14.67	23.25	23.02
$GA_3 \times 10^{-3}$	4.38	6.02	13.31	21.12	20.39
$GA_3 \times 10^{-2}$	3.90	5.53	12.93	20.84	20.15
C.D. at 5%	0.39	0.48	0.29	0.19	0.69

Table 37. Effect of leaf-applied gibberellic acid on underground plant fresh weight and dry weight per plant of *Mentha arvensis* L. at five stages

Spray concentrations (M)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Underground plant fresh weight (g plant^{-1})		
GA_3 (0)	3.00	5.26	10.80	13.40	13.07
$GA_3 \times 10^{-4}$	4.43	8.50	13.47	16.40	15.90
$GA_3 \times 10^{-3}$	3.62	5.83	11.50	14.00	13.33
$GA_3 \times 10^{-2}$	3.00	4.97	10.17	13.23	12.27
C.D. at 5%	0.13	1.37	1.00	0.85	0.39
			Underground plant dry weight (g plant^{-1})		
GA_3 (0)	0.68	1.17	2.40	2.98	2.90
$GA_3 \times 10^{-4}$	0.98	1.89	2.99	3.64	3.53
$GA_3 \times 10^{-3}$	0.80	1.29	2.55	3.11	2.96
$GA_3 \times 10^{-2}$	0.67	1.04	2.26	2.94	2.72
C.D. at 5%	0.13	0.30	0.18	0.19	0.25

4.3.2 Physiological characteristics

4.3.2.1 Photosynthetic characteristics

The photosynthetic characteristics studied at various growth stages were affected significantly by GA_3 application (Table 38-39).

4.3.2.1.1 Chlorophyll content

Significant maximum value was recorded for 10^{-4}M GA_3 at 90, 105, 135 and 150 DAP but at 120 DAP, maximum value for 10^{-4}M GA_3 was equalled by that for 10^{-3}M GA_3. The significant minimum value was recorded for water-sprayed control (W_0) at all stages of sampling except at 120 DAP, at which it was equal to 10^{-2}M GA_3. The per cent increase in chlorophyll content resulted from 10^{-4}M GA_3 over water-sprayed control at 90, 105, 120, 135 and 150 DAP was 23.58, 24.37, 14.20, 15.21 and 18.75 per cent respectively (Table 38).

4.3.2.1.2 Chlorophyll harvest

Maximum value was recorded for 10^{-4}M GA_3 at all samplings but at 90 DAP its effect was equal with that of 10^{-3}M GA_3. The significant minimum value was registered for water-sprayed control (W_0) at all stages. Treatment GA_3 at 10^{-4}M gave 41.08, 56.47, 34.11, 23.19 and 41.02 per cent higher value for chlorophyll harvest than the water-sprayed control at 90, 105, 120, 135 and 150 DAP respectively (Table 38).

4.3.2.1.3 Photosynthetic rate

Treatment 10^{-4}M GA_3 gave significant maximum values at all stages. The water-sprayed control (W_0) gave significant minimum value at all stages except 150 DAP at which its value was equalled with that for 10^{-2}M GA_3. The per cent increase in rate of photosynthesis recorded for 10^{-4}M GA_3 was 20.79, 11.09, 18.13, 16.54 and 17.04 over the water-sprayed control at 90, 105, 120, 135 and 150 DAP respectively (Table 39).

4.3.2.1.4 Stomatal conductance

Maximum value was recorded for 10^{-4}M GA_3 and the value differed significantly from the values given by other treatments of GA_3 at all samplings. Significant minimum value was recorded for the water-sprayed control (W_0) at 90 and 105 DAP but was equalled by that for 10^{-2}M GA_3 at 135 and 150 DAP and also by

Table 38. Effect of leaf-applied gibberellic acid on chlorophyll content and chlorophyll harvest of *Mentha arvensis* L. at five stages

Spray concentrations (M)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
	Chlorophyll content (mg g^{-1} fresh weight)				
GA_3 (0)	1.06	1.19	1.62	2.17	1.92
$GA_3 \times 10^{-4}$	1.31	1.48	1.85	2.50	2.28
$GA_3 \times 10^{-3}$	1.19	1.35	1.76	2.32	2.17
$GA_3 \times 10^{-2}$	1.12	1.30	1.64	2.26	2.10
C.D. at 5%	0.04	0.02	0.10	0.04	0.02
	Chlorophyll harvest (mg . cm^2)				
GA_3 (0)	594	1484	5119	11831	8627
$GA_3 \times 10^{-4}$	838	2322	6865	14575	12166
$GA_3 \times 10^{-3}$	758	2028	6476	13159	11206
$GA_3 \times 10^{-2}$	712	1825	5899	12611	10786
C.D. at 5%	43.57	60.11	99.00	88.93	52.24

that for 10^{-3}M GA_3 at 120 DAP. Treatment 10^{-4}M GA_3 increased stomatal conductance by 5.98, 4.63, 5.34, 6.53 and 5.96 per cent over the water-sprayed control at 90, 105, 120, 135 and 150 DAP, respectively (Table 39).

4.3.2.1.5 Photosynthetic water use efficiency

Maximum value was recorded for 10^{-4}M GA_3, however its value differed significantly from all values at each stage of sampling. Significant lowest value was recorded for the water-sprayed control (W_0) at 90, 105, 120 and 135 DAP but was equal with 10^{-2}M GA_3 at 150 DAP. The per cent increase in photosynthetic water use efficiency was 13.91, 8.58, 12.17, 9.41 and 10.45 over the water-sprayed control at 90, 105, 120, 135 and 150 DAP, respectively (Table 39).

4.3.2.2 Nutrient contents in plant

No significant effect of spray of GA_3 on nutrient content at each stage was observed (Table 40).

4.3.2.2.1 Nitrogen content

The effect of treatments on nitrogen content was non-significant at all stages of sampling (Table 40).

4.3.2.2.2 Phosphorus content

Phosphorus content of plants was not affected by treatments of GA_3 at all stages (Table 40).

4.3.2.2.3 Potassium content

The data recorded for potassium content of plants was also found to be non-significant (Table 40).

4.3.2.3 Nutrient uptake

Spray of GA_3 affected nutrient uptake at all stages significantly (Table 41).

4.3.2.3.1 Nitrogen uptake

Maximum value was recorded for 10^{-4}M GA_3, and its effect was significant at all stages. The significant lowest value was recorded for the water-sprayed control (W_0) at 105 and 135 DAP but equalled by those for 10^{-2}M GA_3 at 90 and 150 DAP and at 120 DAP also for 10^{-3}M GA_3. Treatment 10^{-4}M GA_3 gave in 56.07, 57.64, 38.30, 21.33 and 21.88 per cent more nitrogen uptake than the water-sprayed control at 90, 105, 120, 135 and 150 DAP, respectively (Table 41).

Table 39. Effect of leaf-applied gibberellic acid on photosynthetic rate, stomatal conductance and photosynthetic water use efficiency of *Mentha arvensis* L. at five stages

Spray concentrations (M)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Photosynthetic rate (μ mol CO_2 m^{-2} s^{-1})		
GA_3 (0)	9.38	12.44	15.77	21.89	21.24
$GA_3 \times 10^{-4}$	11.33	13.82	18.63	25.51	24.86
$GA_3 \times 10^{-3}$	10.46	13.42	16.74	23.90	23.17
$GA_3 \times 10^{-2}$	10.18	12.94	16.18	22.69	21.57
C.D. at 5%	0.31	0.27	0.17	0.30	0.40
			Stomatal conductance (mol m^{-2} s^{-1})		
GA_3 (0)	0.234	0.259	0.281	0.306	0.302
$GA_3 \times 10^{-4}$	0.248	0.271	0.296	0.326	0.320
$GA_3 \times 10^{-3}$	0.240	0.265	0.287	0.318	0.310
$GA_3 \times 10^{-2}$	0.237	0.263	0.283	0.310	0.304
C.D. at 5%	0.001	0.002	0.006	0.005	0.003
			Photosynthetic water use efficiency (μ mol mol^{-1})		
GA_3 (0)	40.12	48.03	56.12	71.53	70.33
$GA_3 \times 10^{-4}$	45.70	52.15	62.95	78.26	77.68
$GA_3 \times 10^{-3}$	43.60	50.65	58.32	75.15	74.74
$GA_3 \times 10^{-2}$	42.95	49.20	57.16	73.21	70.97
C.D. at 5%	1.14	1.01	0.62	0.31	1.32

Table 40. Effect of leaf-applied gibberellic acid on nitrogen, phosphorus and potassium content of *Mentha arvensis* L. at five stages

Spray concentrations (M)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Nitrogen (%)		
GA_3 (0)	3.19	3.01	2.65	2.19	1.75
$GA_3 \times 10^{-4}$	3.20	3.15	2.78	2.20	1.74
$GA_3 \times 10^{-3}$	3.17	3.13	2.60	2.13	1.68
$GA_3 \times 10^{-2}$	3.18	3.08	2.58	2.10	1.68
C.D. at 5%	NS	NS	NS	NS	NS
			Phosphorus (%)		
GA_3 (0)	0.382	0.317	0.291	0.241	0.195
$GA_3 \times 10^{-4}$	0.389	0.310	0.280	0.245	0.187
$GA_3 \times 10^{-3}$	0.375	0.315	0.285	0.256	0.184
$GA_3 \times 10^{-2}$	0.393	0.320	0.290	0.240	0.192
C.D. at 5%	NS	NS	NS	NS	NS
			Potassium (%)		
GA_3 (0)	3.16	2.58	2.27	2.09	1.56
$GA_3 \times 10^{-4}$	3.25	2.50	2.26	2.15	1.64
$GA_3 \times 10^{-3}$	3.13	2.52	2.29	2.13	1.70
$GA_3 \times 10^{-2}$	3.20	2.48	2.32	2.11	1.68
C.D. at 5%	NS	NS	NS	NS	NS

4.3.2.3.2 Phosphorus uptake

Significantly maximum value was registered for 10^{-4}M GA_3 at all samplings. The water-sprayed control (W_0) gave significant lowest value at 90, 105 and 135 DAP but was equal to 10^{-2}M GA_3 and 10^{-3}M GA_3 at 120 and 150 DAP, respectively in effect. The per cent increase in phosphorus uptake due to 10^{-4}M GA_3 over the water-sprayed control was 58.04, 46.84, 26.60, 31.36 and 17.37 at 90, 105, 120, 135 and 150 DAP, respectively (Table 41).

4.3.2.3.3 Potassium uptake

Treatment 10^{-4}M GA_3 gave maximum value for potassium uptake at all stages. Significantly lowest value was recorded for the water-sprayed control at 90, 135 and 150 DAP but its lowest value was equalled by those for 10^{-2}M GA_3 at 105 and 120 DAP. Treatment 10^{-4}M GA_3 increased potassium uptake by 60.38, 45.16, 31.23, 17.39 and 28.67 per cent over the water-sprayed control at 90, 105, 120, 135 and 150 DAP, respectively (Table 41).

4.3.3 Yield characteristics

Yield characteristics at all stages were affected significantly by GA_3 application (Tables 42-44).

4.3.3.1 Leaf number per plant

Increasing levels of leaf-applied GA_3 improved leaf number linearly at all stages with 10^{-2}M GA_3 giving 20.37, 74.71, 86.73, 73.18 and 72.06 per cent and higher value 10^{-4}M GA_3, 14.81, 60.92, 58.29, 48.04 and 45.59 per cent higher values compared with the control at 90, 105, 120, 135 and 150 DAP, respectively (Table 42).

4.3.3.2 Branch number per plant

Treatment 10^{-2}M GA_3 produced maximum number of branches at 90, 105, 120 and 135 DAP while at 150 DAP, its effect was at par with that of 10^{-3}M GA_3. GA_3 at 10^{-2}M had significant difference at 120 and 135 DAP from all those for other treatments. However, at 90 and 105 DAP, both treatments viz. 10^{-2}M GA_3 and 10^{-3}M GA_3 were statistically equal in effect. Significant lowest value was recorded for water-sprayed control (W_0) at all samplings. Treatment 10^{-2}M GA_3 increased branch number by 77.35, 120.00, 70.36, 84.05 and 77.89 per cent and 10^{-4}M GA_3, 40.92,

Table 41. Effect of leaf-applied gibberellic acid on nitrogen, phosphorus and potassium uptake of *Mentha arvensis* L. at five stages.

Spray concentrations (M)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Nitrogen (mg plant^{-1})		
GA_3 (0)	107	144	295	422	329
$GA_3 \times 10^{-4}$	167	227	408	512	401
$GA_3 \times 10^{-3}$	139	188	347	450	342
$GA_3 \times 10^{-2}$	124	176	334	438	337
C.D. at 5%	19.00	20.00	21.00	10.00	11.00
			Phosphorus (mg plant^{-1})		
GA_3 (0)	12.87	15.20	32.40	43.36	36.68
$GA_3 \times 10^{-4}$	20.34	22.32	41.02	56.96	43.05
$GA_3 \times 10^{-3}$	16.42	18.96	37.93	51.74	37.52
$GA_3 \times 10^{-2}$	15.33	17.70	37.50	50.02	38.69
C.D. at 5%	0.93	1.46	1.22	1.01	1.05
			Potassium (mg plant^{-1})		
GA_3 (0)	106	124	253	414	293
$GA_3 \times 10^{-4}$	170	180	332	486	377
$GA_3 \times 10^{-3}$	137	152	305	450	347
$GA_3 \times 10^{-2}$	125	137	300	440	338
C.D. at 5%	13.00	11.00	13.00	14.00	13.00

95.53, 47.28, 61.06 and 60.57 per cent over the water-sprayed control at 90, 105, 120, 135 and 150 DAP respectively (Table 42).

4.3.3.3 Leaf yield per plant

Treatment 10^{-4}M GA_3 gave maximum values at all samplings. On the other hand, significant lowest value was recorded for the water-sprayed control (W_0). Treatment 10^{-4}M GA_3 gave 52.31, 33.41, 23.16, 14.18 and 17.90 per cent higher leaf yield over the water-sprayed control at 90, 105, 120, 135 and 150 DAP respectively (Table 43).

4.3.3.4 Stem yield per plant

Maximum value recorded for 10^{-4}M GA_3, was significantly higher than those values given by other treatments of GA_3 at all samplings. The water-sprayed control (W_0) gave significantly lowest value. Treatment 10^{-4}M GA_3 increased stem yield by 49.25, 50.79, 26.79, 27.21 and 30.01 per cent in comparison with water-sprayed control at 90, 105, 120, 135 and 150 DAP respectively (Table 43).

4.3.3.5 Herb yield per plant

The effect of spray treatments of GA_3 on herb yield was significant. Treatment 10^{-4}M GA_3 gave significant maximum values at all samplings. Minimum value was recorded for the water-sprayed control (W_0) and the effect was found significant at all stages. The increase in herb yield resulted from the application of 10^{-4}M GA_3 over the water-sprayed control was 56.97, 49.86, 31.50, 20.64 and 22.36 per cent at 90, 105, 120, 135 and 150 DAP respectively (Table 43).

4.3.3.6 Oil content

Significant maximum values for oil content was registered for 10^{-4}M GA_3 at 105, 120 and 150 DAP but at 90 and 135 DAP, its maximum value was equalled by that for 10^{-3}M GA_3. The effect of the water-sprayed (W_0) control was significantly lowest at final three stages of sampling viz. 120, 135 and 150 DAP but at initial two stages, it was equalled by that for 10^{-2}M GA_3. Treatment 10^{-4}M GA_3 gave 7.14, 28.00, 27.59, 26.25 and 24.68 per cent higher value for oil content in comparison with the water-sprayed control at 90, 105, 120, 135 and 150 DAP respectively (Table 44).

Table 42. Effect of leaf-applied gibberellic acid on leaf number and branch number of *Mentha arvensis* L. at five stages

Spray concentrations (M)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Leaf number plant^{-1}		
GA_3 (0)	54	87	211	358	340
$GA_3 \times 10^{-4}$	62	140	334	530	495
$GA_3 \times 10^{-3}$	63	147	364	580	534
$GA_3 \times 10^{-2}$	65	152	394	620	585
C.D. at 5%	4.20	12.07	15.29	13.41	14.79
			Branch number plant^{-1}		
GA_3 (0)	7.33	15.00	30.33	37.67	34.67
$GA_3 \times 10^{-4}$	10.33	29.33	44.67	60.67	55.67
$GA_3 \times 10^{-3}$	11.67	31.33	48.67	65.33	61.67
$GA_3 \times 10^{-2}$	13.00	33.00	51.67	69.33	61.67
C.D. at 5%	2.68	2.70	2.38	1.66	4.28

Table 43. Effect of leaf-applied gibberellic acid on leaf yield, stem yield and herb yield of *Mentha arvensis* L. at five stages

Spray concentrations (M)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Leaf yield (g plant^{-1})		
GA_3 (0)	7.57	11.52	25.52	43.73	42.07
$GA_3 \times 10^{-4}$	11.53	17.17	34.73	49.93	49.60
$GA_3 \times 10^{-3}$	10.53	14.53	30.40	45.63	43.23
$GA_3 \times 10^{-2}$	9.20	13.48	29.63	45.20	43.13
C.D. at 5%	0.60	0.35	0.67	1.03	0.59
			Stem yield (g plant^{-1})		
GA_3 (0)	7.37	10.10	24.67	43.00	41.53
$GA_3 \times 10^{-4}$	11.00	15.23	31.28	54.70	54.00
$GA_3 \times 10^{-3}$	9.17	12.57	29.48	49.43	48.52
$GA_3 \times 10^{-2}$	8.27	11.47	28.56	48.60	47.53
C.D. at 5%	0.53	0.64	0.96	0.93	1.02
			Herb yield (g plant^{-1})		
GA_3 (0)	14.99	21.62	50.19	86.73	84.67
$GA_3 \times 10^{-4}$	23.53	32.40	66.00	104.63	103.60
$GA_3 \times 10^{-3}$	19.70	27.10	59.88	95.06	91.75
$GA_3 \times 10^{-2}$	17.57	24.90	58.19	93.80	90.66
C.D. at 5%	0.34	0.34	1.30	0.86	1.28

4.3.3.7 Oil yield per plant

Maximum value for oil yield was given by 10^{-4}M GA_3 and the value differed significantly from the values recorded for all other treatments at all stages of sampling. ~~Minimum~~ significant value was registered for the water-sprayed control (W_0) at 90, 120, 135 and 150 DAP but its value was equalled by that for 10^{-2}M GA_3 at 105 DAP. GA_3 at 10^{-4}M gave 63.21, 90.80, 73.65, 44.17 and 47.02 per cent higher oil yield over the water-sprayed control at 90, 105, 120, 135 and 150 DAP, respectively (Table 44).

4.4 Experiment 4

This experiment was conducted to investigate the effect of foliar application of various treatments of Kinetin, viz. 10^{-6}M, 10^{-5}M, 10^{-4}M and water-sprayed control (W_0) on the performance of *Mentha arvensis* L.

The characteristics studied at various sampling stages were the same as in Experiment 1, 2 and 3. The results (Tables 45-56) are summarized below.

4.4.1 Growth characteristics

Effect of various treatments of Kn on growth characteristics at all stages ~~was~~ were significant, except leaf area ratio at 105 DAP and specific leaf weight at 150 DAP (Tables 45-49).

4.4.1.1 Plant height

Treatment 10^{-5}M Kn proved best at all stages except 135 DAP at which, 10^{-6}M Kn gave a maximum value. Significant ~~minimum~~ low value ~~was~~ were recorded for the water-sprayed control (W_0) at all samplings. The increase in plant height resulted from application of 10^{-5}M Kn over the water-sprayed control at 90, 105, 120, 135 and 150 DAP was 12.39, 9.48, 28.58, 20.27 and 27.05 per cent respectively (Table 45).

4.4.1.2 Root length

The effect of 10^{-5}M Kn gave a significant maximum value for root length. The effect of the water-sprayed control (W_0) was significantly lowest at all sampling stages. Treatment 10^{-5}M Kn had 50.05, 64.34, 35.67, 50.77 and 47.34 per cent higher value as compared with the water-sprayed control at 90, 105, 120, 135 and 150 DAP, respectively (Table 45).

Table 44. Effect of leaf-applied gibberellic acid on oil content and oil yield of *Mentha arvensis* L. at five stages

Spray concentrations (M)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Oil content (%) (w/w)		
GA_3 (0)	0.42	0.50	0.58	0.80	0.77
$GA_3 \times 10^{-4}$	0.45	0.64	0.74	1.01	0.96
$GA_3 \times 10^{-3}$	0.44	0.55	0.69	0.95	0.90
$GA_3 \times 10^{-2}$	0.42	0.53	0.65	0.91	0.83
C.D. at 5%	0.01	0.03	0.04	0.06	0.05
			Oil yield (g $plant^{-1}$)		
GA_3 (0)	3.18	5.76	14.80	34.98	32.39
$GA_3 \times 10^{-4}$	5.53	10.99	25.70	50.43	47.62
$GA_3 \times 10^{-3}$	4.84	8.57	20.98	43.35	38.91
$GA_3 \times 10^{-2}$	4.05	7.55	19.26	41.13	35.80
C.D. at 5%	0.29	0.72	0.27	1.16	0.92

Table 45. Effect of leaf-applied kinetin on plant height and root length of *Mentha arvensis* L. at five stages

Spray concentrations (M)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Plant height (cm)		
Kn (0)	33.66	44.00	47.83	61.67	56.67
Kn × 10^{-6}	37.50	47.67	58.33	74.67	71.83
Kn × 10^{-5}	37.83	48.17	61.50	74.17	72.00
Kn × 10^{-4}	36.00	46.67	52.00	67.67	64.00
C.D. at 5%	0.69	0.76	1.95	1.19	1.37
			Root length (cm)		
Kn (0)	10.33	12.17	18.67	22.00	21.17
Kn × 10^{-6}	14.00	17.00	24.00	31.17	27.33
Kn × 10^{-5}	15.50	20.00	25.33	33.17	31.17
Kn × 10^{-4}	11.50	16.00	19.50	26.50	24.00
C.D. at 5%	0.76	1.12	0.69	1.01	0.44

4.4.1.3 Leaf area per plant

Among applied treatments of Kn, 10^{-5}M Kn gave significant higher values in comparison with all other treatments at 105, 120, 135 and 150 DAP, while at 90 DAP, its higher values showed equal effect with that of 10^{-6}M Kn. Significantly lowest values was recorded for the water-sprayed control (W_0) at all stages. The per cent increase in leaf area due to 10^{-5}M Kn over the water-sprayed control was 46.76, 59.04, 41.02, 44.55 and 43.33 at 90, 105, 120, 135 and 150 DAP respectively (Table 46).

4.4.1.4 Leaf area ratio

Among all applied treatments of Kn, 10^{-5}M Kn and 10^{-6}M Kn gave significant maximum values at 90 and 150 DAP respectively. However, 10^{-5}M Kn and 10^{-6}M Kn at 135 DAP and 10^{-5}M Kn and 10^{-4}M Kn at 120 DAP were equally effective. At 105 DAP, the effect was found non significant. Minimum value was recorded for the water-sprayed control (W_0) and the value showed significant difference from the values recorded for other treatments. The increase in specific leaf area ratio due to 10^{-5}M Kn over the water-sprayed control was 23.00, 62.18, 5.55, 13.52 and 15.62 per-cent at 90, 105, 120, 135 and 150 DAP respectively (Table 46).

4.4.1.5 Specific leaf area

Maximum values was recorded for 10^{-5}M Kn at 90, 105 and 150 DAP while at 120 and 135 DAP, 10^{-6}M Kn had maximum value. The values given by 10^{-5}M Kn and 10^{-6}M Kn were statistically equal at 120, 135 and 150 DAP. Significant minimum values was registered for the water-sprayed control (W_0) at all stages. The increase in specific leaf area due to 10^{-5}M Kn over the water-sprayed control was 14.93, 24.05, 6.25, 23.52 and 22.13 per cent at 90, 105, 120, 135 and 150 DAP respectively (Table 46).

4.4.1.6 Leaf dry weight

Treatment 10^{-5}M Kn gave maximum value for leaf dry weight and its effect was significant at 120 and 150 DAP but at 90, 105 and 135 DAP it was equalled by that for 10^{-6}M kn. Significant lowest values was recorded for the water-sprayed control (W_0) at 90, 105, 120 and 150 DAP while at 135 DAP, its value was equal led by that for 10^{-4}M Kn. The per cent increase in leaf dry weight due to

Table 46. Effect of leaf-applied kinetin on leaf area, leaf area ratio and specific leaf area of *Mentha arvensis* L. at five stages

Spray concentrations (M)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Leaf area (cm^2 $plant^{-1}$)		
Kn (0)	494	1062	2928	5320	5207
Kn × 10^{-6}	657	1608	3767	7287	7191
Kn × 10^{-5}	725	1689	4129	7690	7463
Kn × 10^{-4}	561	1271	3322	6390	6146
C.D. at 5%	52.00	72.00	118.00	69.00	110.00
			Leaf area ratio (cm^2g^{-1})		
Kn (0)	236.91	474.11	543.23	586.55	578.55
Kn × 10^{-6}	272.75	472.94	559.73	672.85	668.93
Kn × 10^{-5}	291.41	474.43	573.47	665.80	651.79
Kn × 10^{-4}	259.25	476.02	569.81	635.82	615.21
C.D. at 5%	12.73	NS	8.87	13.12	11.83
			Specific leaf area (cm^2g^{-1})		
Kn (0)	226.73	332.91	501.38	548.51	544.12
Kn × 10^{-6}	243.04	395.07	539.66	681.06	661.54
Kn × 10^{-5}	260.59	412.96	532.73	677.50	664.56
Kn × 10^{-4}	255.02	385.15	521.44	625.25	604.89
C.D. at 5%	5.51	6.69	12.65	14.45	11.83

10^{-5}M Kn over the water-sprayed control at 90, 105, 120, 135 and 150 DAP was 35.65, 36.79, 24.01, 13.71 and 13.66 respectively (Table 47).

4.4.1.7 Specific leaf weight

The effect of 10^{-6}M Kn gave significant maximum value at 90 DAP. However at 105, 120 and 135 DAP, the water-sprayed control (W_0) gave maximum value and was equal in effect with that of 10^{-4}M Kn at 105 DAP, and also with that of 10^{-6}M Kn at 120 DAP while at 135 DAP, it showed significant effect from other treatments. On the other hand, 10^{-5}M Kn gave ~~minimum~~ low value at 105, 120 and 135 DAP, and its effect was equal to that of 10^{-6}M Kn at 105, 120 DAP and also to 10^{-4}M Kn at 135 DAP. The data were non-significant at 150 DAP. The per cent decrease in specific leaf weight resulted from 10^{-5}M Kn in comparison with the water-sprayed control was 37.93, 13.71 and 26.53 at 105, 120 and 135 DAP respectively (Table 47).

4.4.1.8 Stem dry weight

Maximum value was recorded for 10^{-5}M Kn and the value differed significantly from all other values at 120, 135 and 150 DAP but showed equal effect with that for 10^{-6}M Kn at 90 and 105 DAP. The ~~significant~~ lowest effect was recorded for the water-sprayed control (W_0) at all samplings. Treatment 10^{-5}M Kn increased stem dry weight by 56.74, 58.93, 33.58, 27.34 and 27.22 per cent over the water-sprayed control at 90, 105, 120, 135 and 150 DAP respectively (Table 48).

4.4.1.9 Aboveground plant dry weight

Treatment 10^{-5}M Kn gave maximum value at all stages. Significant minimum value ~~was~~ were recorded for the water sprayed control (W_0) at all stages. The per cent increase in plant dry weight resulted from 10^{-5}M Kn over the water-sprayed control was 50.49, 56.79, 28.88, 19.04 and 27.89 at 90, 105, 120, 135 and 150 DAP respectively (Table 48).

4.4.1.10 Underground plant fresh weight

Treatment 10^{-6}M Kn proved best. The lowest value was recorded for the water-sprayed control (W_0). The per cent increase in under ground plant fresh weight resulted from 10^{-5}M Kn was 87.50, 78.57, 60.68, 71.35 and 76.53 and from 10^{-6}M Kn was 80.75, 77.14, 60.08, 70.96 and 75.00 per cent over the water-sprayed control at 90, 105, 120, 135 and 150 DAP respectively (Table 49).

Table 47. Effect of leaf-applied kinetin on leaf dry weight and specific leaf weight of *Mentha arvensis* L. at five stages

Spray concentrations (M)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Leaf dry weight (g plant^{-1})		
Kn (0)	2.30	2.19	5.83	9.92	9.57
Kn × 10^{-6}	3.12	4.07	6.97	10.92	10.87
Kn × 10^{-5}	3.12	4.09	7.23	11.28	11.23
Kn × 10^{-4}	2.45	3.30	6.36	10.22	10.15
C.D. at 5%	0.12	0.09	0.11	0.45	0.18
			Specific leaf weight (mg cm^{-2})		
Kn (0)	3.76	2.82	1.99	1.86	1.83
Kn × 10^{-6}	4.75	2.53	1.85	1.50	1.51
Kn × 10^{-5}	4.30	2.42	1.75	1.47	1.50
Kn × 10^{-4}	4.36	2.60	1.91	1.60	1.65
C.D. at 5%	0.30	0.21	0.17	0.20	NS

Table 48. Effect of leaf-applied kinetin on stem dry weight and aboveground plant dry weight of *Mentha arvensis* L. at five stages.

Spray concentrations (M)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Stem dry weight (g plant^{-1})		
Kn (0)	1.78	2.24	5.39	9.07	9.00
Kn × 10^{-6}	2.78	3.40	6.73	10.83	10.75
Kn × 10^{-5}	2.79	3.56	7.20	11.55	11.45
Kn × 10^{-4}	2.41	2.67	5.83	10.05	9.99
C.D. at 5%	0.32	0.16	0.27	0.30	0.23
			Aboveground plant dry weight (g plant^{-1})		
Kn (0)	4.08	5.23	11.98	19.20	19.00
Kn × 10^{-6}	6.13	8.01	14.67	23.28	23.17
Kn × 10^{-5}	6.14	8.20	15.44	24.43	24.30
Kn × 10^{-4}	5.05	6.40	13.04	21.68	21.57
C.D. at 5%	0.06	0.15	0.35	0.19	0.17

4.4.1.11 Underground plant dry weight

Among treatments of Kn, 10^{-6}M Kn proved best for underground plant dry weight at each stage. Significant minimum value was recorded for the water-sprayed control (W_0). The per cent increase due to 10^{-6}M Kn over the control was 81.82, 78.57, 60.00, 73.49 and 75.08 at 90, 105, 120, 135 and 150 DAP, respectively. Moreover treatment 10^{-5}M Kn increased underground plant dry weight by 88.64, 79.87, 60.77, 73.49 and 76.58 per cent over the water-sprayed control at 90, 105, 120, 135 and 150 DAP respectively (Table 49).

4.4.2 Physiological characteristics

4.4.2.1 Photosynthetic characteristics

Effect of kinetin on photosynthetic characteristics at each stage was significant (Tables 50-51).

4.4.2.1.1 Chlorophyll content

Treatment 10^{-5}M Kn gave significant maximum value at 135 and 150 DAP. However, maximum value for 10^{-5}M Kn at 90, 105 and 120 DAP was equalled by that for 10^{-6}M Kn. Minimum values was recorded for the water-sprayed control (W_0) at all stages but the value was equalled by that for 10^{-4}M Kn at 90 and 105 DAP. Treatment 10^{-5}M Kn increased chlorophyll content by 11.50, 6.72, 6.29, 4.67 and 7.46 per cent over the water-sprayed control at 90, 105, 120, 135 and 150 DAP, respectively (Table 50).

4.4.2.1.2 Chlorophyll harvest

Treatment 10^{-5}M Kn gave significant maximum value for chlorophyll harvest. The water-sprayed control (W_0) gave significantly minimum values at 105, 120, 135 and 150 DAP but at 90 DAP, its minimum value was equalled by that for 10^{-4}M Kn. Treatment 10^{-5}M Kn gave 63.56, 132.27, 48.25, 51.31 and 54.02 per cent higher value than the water-sprayed control at 90, 105, 120, 135 and 150 DAP, respectively (Table 50).

4.4.2.1.3 Photosynthetic rate

Rate of photosynthesis was affected by all sprayed treatments of Kn significantly. Significant maximum values was recorded for 10^{-5}M Kn at all samplings. The water-sprayed control (W_0) gave significantly minimum value. Treatment 10^{-5}M

Table 49. Effect of leaf-applied kinetin on underground plant fresh weight and dry weight per plant of *Mentha arvensis* L. at five stages.

Spray concentrations (M)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
	Underground plant fresh weight (g plant^{-1})				
Kn (0)	4.00	7.00	11.70	15.60	15.00
Kn × 10^{-6}	7.23	12.40	18.73	26.67	26.25
Kn × 10^{-5}	7.50	12.50	18.80	26.73	26.48
Kn × 10^{-4}	5.70	9.80	15.73	23.80	23.46
C.D. at 5%	0.42	0.39	0.40	0.79	1.18
	Underground plant dry weight (g plant^{-1})				
Kn (0)	0.88	1.54	2.60	3.47	3.33
Kn × 10^{-6}	1.60	2.75	4.16	6.02	5.83
Kn × 10^{-5}	1.66	2.77	4.18	5.94	5.88
Kn × 10^{-4}	1.26	2.16	3.49	5.29	5.21
C.D. at 5%	0.09	0.09	0.10	0.28	0.13

Table 50. Effect of leaf-applied kinetin on chlorophyll content and chlorophyll harvest of *Mentha arvensis* L. at five stages

Spray concentrations (M)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
	Chlorophyll content (mg g^{-1} fresh weight)				
Kn (0)	1.13	1.34	1.75	2.14	2.01
Kn × 10^{-6}	1.21	1.40	1.86	2.21	2.11
Kn × 10^{-5}	1.26	1.43	1.84	2.24	2.16
Kn × 10^{-4}	1.17	1.37	1.78	2.18	2.09
C.D. at 5%	0.07	0.05	0.02	0.02	0.04
	Chlorophyll harvest (mg . cm^2)				
Kn (0)	558.60	1423.08	5124.09	11383.75	10466.35
Kn × 10^{-6}	795.17	2251.20	7006.32	16105.13	15173.01
Kn × 10^{-5}	913.65	2415.27	7596.73	17224.73	16120.08
Kn × 10^{-4}	656.64	1741.27	5912.36	13930.44	12844.58
C.D. at 5%	122.50	144.25	114.77	181.68	141.80

Kn increased photosynthetic rate by 13.26, 15.08, 25.88, 22.27 and 21.94 per cent respectively over the control at 90, 105, 120, 135 and 150 DAP, respectively (Table 51).

4.4.2.1.4 Stomatal conductance

Spray treatment 10^{-5}M Kn gave significant maximum value for stomatal conductance at 105, 120, 135 and 150 DAP but at 90 DAP its value was equalled by that for 10^{-6}M Kn and 10^{-4}M Kn. Significantly lowest value was recorded for the water-sprayed control (W_0) at all stages except at 105 DAP, its value was equalled by that for 10^{-4}M Kn. The per cent increase in stomatal conductance recorded for 10^{-5}M Kn was 5.08, 4.56, 5.30, 7.95 and 7.48 per cent over the water-sprayed control at 90, 105, 120, 135 and 150 DAP, respectively (Table 51).

4.4.2.1.5 Photosynthetic water use efficiency

Photosynthetic water use efficiency was affected significantly by Kn application. Maximum value was recorded for 10^{-5}M Kn and the value differed significantly from the values for other treatments. Significantly lowest value was recorded for the water-sprayed control (W_0) at all stages of sampling. Treatment 10^{-5}M Kn gave 11.33, 10.10, 19.55, 13.27 and 13.44 per cent higher value for photosynthetic water use efficiency than the water-sprayed control at 90, 105, 120, 135 and 150 DAP, respectively (Table 51).

4.4.2.2 Nutrient contents in plant

Nutrient contents at each stage were not affected significantly by Kn treatments (Table 52).

4.4.2.2.1 Nitrogen content

The effect of Kn treatments on nitrogen content was non-significant (Table 52).

4.4.2.2.2 Phosphorus content

Phosphorus content was not found to be affected significantly by Kn treatments (Table 52).

4.4.2.2.3 Potassium content

There was no significant effect of Kn treatments on potassium content in plants (Table 52).

Table 51. Effect of leaf-applied kinetin on photosynthetic rate, stomatal conductance and photosynthetic water use efficiency of *Mentha arvensis* L. at five stages

Spray concentrations (M)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Photosynthetic rate (μ mol CO_2 m^{-2} s^{-1})		
Kn (0)	9.48	12.73	15.92	21.24	20.56
Kn × 10^{-6}	10.80	14.25	19.39	24.30	23.48
Kn × 10^{-5}	11.10	14.65	20.04	25.97	25.07
Kn × 10^{-4}	10.24	13.35	17.44	23.06	22.05
C.D. at 5%	0.20	0.11	0.22	0.35	1.12
			Stomatal conductance (mol m^{-2} s^{-1})		
Kn (0)	0.236	0.263	0.283	0.302	0.294
Kn × 10^{-6}	0.246	0.270	0.294	0.321	0.312
Kn × 10^{-5}	0.248	0.275	0.298	0.326	0.316
Kn × 10^{-4}	0.243	0.266	0.286	0.315	0.302
C.D. at 5%	0.006	0.004	0.001	0.002	0.003
			Photosynthetic water use efficiency (μ mol mol^{-1})		
Kn (0)	40.17	48.39	56.25	70.33	69.93
Kn × 10^{-6}	43.90	52.78	65.95	75.70	75.26
Kn × 10^{-5}	44.72	53.28	67.25	79.66	79.33
Kn × 10^{-4}	42.15	50.19	60.98	73.21	73.01
C.D. at 5%	0.14	0.47	1.06	0.76	0.89

Table 52. Effect of leaf-applied kinetin on nitrogen, phosphorus and potassium content of *Mentha arvensis* L. at five stages

Spray concentrations (M)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Nitrogen (%)		
Kn (0)	3.21	3.04	2.62	2.20	1.70
Kn × 10^{-6}	3.15	3.09	2.48	2.30	1.82
Kn × 10^{-5}	3.25	3.12	2.58	2.29	1.75
Kn × 10^{-4}	3.30	3.06	2.69	2.20	1.82
C.D. at 5%	NS	NS	NS	NS	NS
			Phosphorus (%)		
Kn (0)	0.378	0.323	0.286	0.231	0.185
Kn × 10^{-6}	0.388	0.325	0.290	0.240	0.186
Kn × 10^{-5}	0.390	0.320	0.278	0.245	0.189
Kn × 10^{-4}	0.372	0.323	0.292	0.250	0.192
C.D. at 5%	NS	NS	NS	NS	NS
			Potassium (%)		
Kn (0)	3.13	2.61	2.27	2.16	1.66
Kn × 10^{-6}	3.17	2.59	2.32	2.10	1.63
Kn × 10^{-5}	3.22	2.55	2.30	2.20	1.62
Kn × 10^{-4}	3.14	2.57	2.30	2.18	1.70
C.D. at 5%	NS	NS	NS	NS	NS

4.4.2.3 Nutrient uptake

Kinetin treatments affected nutrient uptake at each stage significantly (Table 53).

4.4.2.3.1 Nitrogen uptake

Maximum value was recorded for 10^{-5}M Kn at all stages but the value was equalled by that for 10^{-6}M Kn at 90 and 105 DAP. Application of 10^{-5}M Kn resulted in 64.46, 63.06, 26.75, 24.22 and 22.83 per cent increase in nitrogen uptake over the water-sprayed control (W_0) at 90, 105, 120, 135 and 150 DAP, respectively (Table 53).

4.4.2.3.2 Phosphorus uptake

Treatment 10^{-5}M Kn gave maximum value at all stages but at 90, 105 and 120 DAP the value was equalled by that for 10^{-6}M Kn. Significantly minimum value was noted for the water-sprayed control (W_0) at all stages. Treatment 10^{-5}M Kn gave 67.60, 56.84, 25.28, 26.64 and 21.93 per cent increase in phosphorus uptake in comparison with the water-sprayed control at 90, 105, 120, 135 and 150 DAP, respectively (Table 53).

4.4.2.3.3 Potassium uptake

Treatment 10^{-5}M Kn gave maximum value at all stages, but it was equal in effect with that of 10^{-6}M Kn at 90 and 105 DAP. Significant minimum value was recorded for the water-sprayed control (W_0) at all stages of crop growth. Application of 10^{-5}M Kn gave 67.80, 54.81, 30.51, 21.72 and 16.57 per cent higher value for potassium uptake in comparison with the water-sprayed control at 90, 105, 120, 135 and 150 DAP, respectively (Table 53).

4.4.3 Yield characteristics

There was significant effect of kinetin on yield characteristics at each stage (Tables 54-56).

4.4.3.1 Leaf number per plant

Significant maximum value was given by 10^{-5}M Kn at all stages. On the other hand, significant lowest value was recorded for the water-sprayed control (W_0). The per cent increase in leaf number resulted from the application of the 10^{-5}M Kn over

Table 53. Effect of leaf-applied kinetin on nitrogen, phosphorus and potassium uptake of *Mentha arvensis* L. at five stages

Spray concentrations (M)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Nitrogen (mg plant^{-1})		
Kn (0)	121	157	314	450	346
Kn × 10^{-6}	193	247	364	535	422
Kn × 10^{-5}	199	256	398	559	425
Kn × 10^{-4}	167	196	351	477	393
C.D. at 5%	12.00	11.00	9.00	12.00	12.00
			Phosphorus (mg plant^{-1})		
Kn (0)	14.29	16.73	34.26	47.26	37.67
Kn × 10^{-6}	23.78	26.03	42.54	55.87	43.10
Kn × 10^{-5}	23.95	26.24	42.92	59.85	45.93
Kn × 10^{-4}	18.79	20.67	38.08	54.20	41.41
C.D. at 5%	1.15	1.42	1.18	1.11	1.18
			Potassium (mg plant^{-1})		
Kn (0)	118	135	272	442	338
Kn × 10^{-6}	194	207	340	489	378
Kn × 10^{-5}	198	209	355	538	394
Kn × 10^{-4}	159	164	300	473	367
C.D. at 5%	11.00	14.00	12.00	13.00	11.00

the water-sprayed control was 38.14, 43.94, 21.21, 30.35 and 29.44 at 90, 105, 120, 135 and 150 DAP respectively (Table 54).

4.4.3.2 Branch number per plant

Among all spray treatments of Kn, 10^{-5}M Kn gave maximum value at all stages, except at 90 DAP at which 10^{-6}M Kn exhibited highest value. At 90 DAP, the effect of 10^{-6}M Kn was at par with that of 10^{-5}M Kn and at 105 and 135 DAP, the effect of 10^{-5}M Kn was equal to that of 10^{-6}M Kn. Significant minimum value was recorded for water-sprayed control (W_0) at all stages, except at 105 DAP, it was equal in effect with of 10^{-4}M Kn. The per cent increase in branch number due to 10^{-5}M Kn was 29.28, 35.71, 58.05, 46.66 and 56.73 compared with the water-sprayed control at 90, 105, 120, 135 and 150 DAP respectively (Table 54).

4.4.3.3 Leaf yield per plant

Treatment 10^{-5}M Kn gave maximum leaf yield per plant at all stages, except at 90 DAP at which 10^{-6}M Kn showed highest effect. However, at 90 and 105 DAP, 10^{-6}M and 10^{-5}M Kn were equally effective. Effect of water-sprayed control (W_0) was significantly lowest at all samplings. The per cent increase in leaf yield due to 10^{-5}M Kn over the water-sprayed control was 67.02, 58.88, 24.09, 13.76 and 32.79 at 90, 105, 120, 135 and 150 DAP respectively (Table 55).

4.4.3.4 Stem yield per plant

Treatment 10^{-5}M Kn exhibited maximum value at all stages, however at 90 DAP, its effect was at par with that of 10^{-6}M Kn. On the other hand, minimum value was recorded for the water-sprayed control (W_0) at all the stages. The increase in stem yield due to 10^{-5}M Kn over the control at 90, 105, 120, 135 and 150 DAP was 56.40, 58.61, 34.02, 25.54 and 27.16 per cent respectively (Table 55).

4.4.3.5 Herb yield per plant

Treatment 10^{-5}M Kn gave maximum value at all stages however at 90 and 105 DAP, its effect was equalled by that of 10^{-6}M Kn. The effect of the water-sprayed control was significantly lowest at all stages of sampling. Application of 10^{-5}M Kn resulted in 62.01, 65.86, 28.85, 19.44 and 19.33 per cent higher herb yield over the water-sprayed control at 90, 105, 120, 135 and 150 DAP respectively (Table 55).

Table 54. Effect of leaf-applied kinetin on leaf number and branch number of *Mentha arvensis* L. at five stages

Spray concentrations (M)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Leaf number plant^{-1}		
Kn (0)	46.33	71.33	204.33	347.00	339.67
Kn × 10^{-6}	58.00	134.00	230.67	428.67	423.00
Kn × 10^{-5}	64.00	142.67	247.67	452.33	439.67
Kn × 10^{-4}	54.33	91.00	216.67	383.33	368.67
C.D. at 5%	2.72	7.43	9.94	14.25	13.14
			Branch number plant^{-1}		
Kn (0)	5.67	14.00	20.67	35.00	32.33
Kn × 10^{-6}	8.00	17.33	28.67	48.67	45.67
Kn × 10^{-5}	7.33	19.00	32.67	51.33	50.67
Kn × 10^{-4}	6.33	14.33	24.67	43.33	38.67
C.D. at 5%	2.42	2.60	1.50	2.68	1.29

Table 55. Effect of leaf-applied kinetin on leaf yield, stem yield and herb yield of *Mentha arvensis* L. at five stages

Spray concentrations (M)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Leaf yield (g plant^{-1})		
Kn (0)	8.40	11.67	26.23	44.63	38.03
Kn × 10^{-6}	14.07	18.33	31.38	49.17	48.95
Kn × 10^{-5}	14.03	18.43	32.55	50.77	50.50
Kn × 10^{-4}	11.07	14.87	28.63	46.00	45.70
C.D. at 5%	0.56	0.39	0.89	0.91	0.80
			Stem yield (g plant^{-1})		
Kn (0)	7.5	10.10	24.10	41.30	40.50
Kn × 10^{-6}	11.67	15.30	30.22	48.60	48.37
Kn × 10^{-5}	11.73	16.02	32.30	51.85	51.50
Kn × 10^{-4}	10.13	12.03	26.13	45.05	44.88
C.D. at 5%	1.32	0.71	1.01	1.26	1.04
			Herb yield (g plant^{-1})		
Kn (0)	15.90	20.77	50.33	85.95	85.55
Kn × 10^{-6}	25.74	33.63	61.60	97.80	97.35
Kn × 10^{-5}	25.76	34.45	64.85	102.66	102.03
Kn × 10^{-4}	21.20	26.90	54.76	91.08	90.60
C.D. at 5%	1.70	2.12	2.81	2.06	1.16

4.4.3.6 Oil content

Maximum value was recorded for 10^{-5}M Kn at all stages, except 90 DAP, at which its effect was at par with that of 10^{-6}M Kn. Significant minimum value was recorded for water-sprayed control (W_0) at all stages except 90 DAP, at which its value was equalled by that for 10^{-4}M Kn. The increase in oil content due to 10^{-5}M Kn over the water-sprayed control was 12.17, 14.58, 45.45, 44.04 and 21.05 per cent at 90, 105, 120, 135 and 150 DAP, respectively (Table 56).

4.4.3.7 Oil yield per plant

Spray treatment 10^{-5}M Kn gave maximum value for oil yield at each stage however at 90 and 105 DAP, its effect was at par with that of 10^{-6}M Kn. Significant lowest value was recorded for the water-sprayed control (W_0) at all sampling stages except 90 DAP, at which it was equal to 10^{-4}M Kn in effect. Treatment 10^{-5}M Kn gave 82.72, 81.07, 80.46, 64.15 and 60.76 per cent increase in oil yield over the water-sprayed control at 90, 105, 120, 135 and 150 DAP, respectively (Table 56).

4.5 Experiment 5

This factorial randomized design experiment was planned to investigate the effect of four levels of soil-applied nitrogen, i.e. 0, 60, 90 and 120 kg/ha (selected on the basis of results of Experiment 1) and foliar spray of 10^{-5}M GA_3, 10^{-4}M GA_3, 10^{-6}M Kn and 10^{-}M Kn alone as well as in combination on growth, physiological and yield characteristics at various stages of crop growth as described in Experiment 1. The results are summarized (Tables 57-85).

4.5.1 Growth characteristics

Effect of nitrogen and phytohormones and of their interaction on all growth characteristics except interaction effect on leaf area ratio, specific leaf area and specific leaf weight at all stages was significant (Tables 57-67).

4.5.1.1 Plant height

Treatment N_{90} gave maximum value at all sampling stages. Minimum value was recorded for the control (N_0) but at 120 DAP N_{60} gave significantly lowest value and at 135 DAP was equal in effect with that of the control (N_0). The per cent increase in plant height resulted from application of N_{90} over the control was 7.37, 9.67, 17.83, 8.25 and 8.62 at 90, 105, 120, 135 and 150 DAP, respectively.

Table 56. Effect of leaf-applied kinetin on oil content and oil yield of *Mentha arvensis* L. at five stages

Spray concentrations (M)	Growth stages (days after planting)				
	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP
			Oil content (%) (w/w)		
Kn (0)	0.42	0.48	0.55	0.79	0.76
Kn × 10^{-6}	0.45	0.53	0.72	0.99	0.85
Kn × 10^{-5}	0.46	0.55	0.80	1.14	0.92
Kn × 10^{-4}	0.41	0.50	0.61	0.87	0.82
C.D. at 5%	0.01	0.01	0.06	0.04	0.03
			Oil yield per plant (g)		
Kn (0)	3.53	5.60	14.43	35.26	28.90
Kn × 10^{-6}	6.33	9.71	22.59	48.68	41.61
Kn × 10^{-5}	6.45	10.14	26.04	57.88	46.46
Kn × 10^{-4}	4.54	7.43	17.46	40.02	37.47
C.D. at 5%	0.93	1.31	1.97	1.95	1.58

As far as effect of phytohormones was concerned, treatment 10^{-4}M GA_3 gave maximum value, and differed significantly from other treatments at 120 DAP. However at 90, 105, 135 and 150 DAP, it was equal to that of 10^{-5}M GA_3 in effect. Significantly lowest value was recorded for the water-sprayed control (W_0). The per-cent increase in plant height resulted from 10^{-4}M GA_3 was 20.63, 27.07, 31.70, 23.82 and 24.03 over the water-sprayed control at 90, 105, 120, 135 and 150 DAP, respectively.

With regard to interaction effect, $N_{90}\times10^{-5}$M GA_3 gave maximum value and equal to that of $N_{120}\times10^{-4}$M GA_3 at 120 DAP and also to $N_{120}\times10^{-5}$M GA_3 and $N_{90}\times10^{-4}$M GA_3 at 90 DAP in effect. However at 105, 135 and 150 DAP, the value differed significantly from those for all other interactions. Lowest value was noted for the control ($N_0\times W_0$) at all sampling stages. The increase in plant height due to $N_{90}\times10^{-5}$M GA_3 over the control was 39.59, 49.19, 75.66, 57.46 and 53.52 per cent at 90, 105, 120, 135 and 150 DAP, respectively (Table 57).

4.5.1.2 Root length

Significant maximum value was recorded for N_{90} at all stages. Control (N_0) showed significantly lowest effect at each sampling. Treatment N_{90} gave 18.82, 23.86, 38.18, 41.11 and 40.00 per cent increase in root length over the control at 90, 105, 120, 135 and 150 DAP, respectively.

Pertaining to phytohormones, 10^{-5}M Kn gave significant maximum value for root length at 90, 105, 135 and 150 DAP. However at 120 DAP, its highest effect was equal to that of 10^{-6}M Kn. The water-sprayed control (W_0) gave significantly lowest value at all samplings. The per cent increase in root length due to 10^{-5}M Kn over the water-sprayed control was 13.93, 36.75, 41.68, 31.31 and 32.04 at 90, 105, 120, 135 and 150 DAP, respectively.

Regarding interaction effect, $N_{90}\times10^{-6}$M Kn gave maximum value and the value was equalled by that for $N_{120}\times10^{-5}$M Kn at 90 and 105 DAP. Whilst at 135 and 150 DAP it was equally effective with $N_{90}\times10^{-5}$M Kn. The value recorded for the control ($N_0\times W_0$) was significantly lowest at 90, 105, 135 and 150 DAP but at 120 DAP, it was statistically equal to that for $N_{60}\times W_0$. The per cent increase in root length

Table 57. Effect of soil-applied nitrogen and leaf-applied phytohormones and of their interaction on plant height (cm) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose N kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
N_0	32.00	42.33	41.00	37.00	37.67	38.00	41.00	54.00	56.50	44.00	45.50	48.20
N_{60}	35.67	38.50	42.83	37.33	37.33	38.33	43.33	53.17	55.00	48.50	48.00	49.60
N_{90}	37.33	44.67	44.17	39.50	38.33	40.80	46.17	61.17	58.13	53.83	53.17	52.87
N_{120}	37.33	44.33	43.67	36.83	37.37	39.91	45.50	50.83	54.00	47.33	50.50	48.63
Mean	35.58	42.46	42.92	37.67	37.68		44.00	54.79	55.91	48.41	49.29	
	120 DAP						135 DAP					
N_0	44.50	61.33	76.17	59.67	59.17	60.17	58.00	86.33	85.00	72.33	73.33	75.10
N_{60}	53.00	63.00	59.50	53.50	55.83	56.97	66.50	72.33	86.33	75.50	75.50	75.23
N_{90}	62.50	78.83	72.17	58.67	63.50	67.13	74.33	91.33	83.67	81.17	77.00	81.50
N_{120}	57.17	61.33	78.17	57.17	57.50	62.27	70.00	82.83	77.87	75.00	78.50	77.24
Mean	54.29	66.12	71.50	57.25	59.00		67.21	83.20	83.22	76.00	76.08	
	150 DAP											
N_0	56.67	83.83	84.83	72.50	73.50	74.27						
N_{60}	66.67	72.50	86.50	75.67	75.67	75.40						
N_{90}	74.53	87.00	84.50	81.33	78.00	81.07						
N_{120}	70.17	82.50	76.63	76.50	79.17	76.99						
Mean	67.01	81.46	83.11	76.50	76.59							

CD at 5%					
	90	105	120	135	150
Nitrogen	0.50	1.08	0.49	0.39	0.79
Phytohormone	0.56	1.21	0.55	0.44	0.81
Interaction	1.13	2.42	1.09	0.85	1.66

due to $N_{90}\times10^{-6}$M Kn over the control was 55.48, 81.22, 102.66, 90.96 and 90.89 per cent at 90, 105, 120, 135 and 150 DAP, respectively (Table 58).

4.5.1.3 Leaf area

Among nitrogen treatments, N_{90} gave maximum values at all stages of crop growth. On the other hand, the control (N_0) gave significantly minimum values. The per cent increase in leaf area recorded due to N_{90} compared with the control was 35.24, 39.74, 42.42, 28.73 and 31.16 at 90, 105, 120, 135 and 150 DAP, respectively.

As far as phytohormones were concerned, treatment 10^{-5}M Kn gave maximum values at all stages, however its effect was equal to that of 10^{-5}M GA_3 at 120 and 135 DAP. Significant minimum value was recorded for the water-sprayed control (W_0). Treatment 10^{-5}M Kn gave 64.93, 84.76, 33.51, 28.92 and 30.21 per cent higher value for leaf area than the water-sprayed control (W_0) at 90, 105, 120, 135 and 150 DAP, respectively.

Regarding interactions, $N_{90}\times10^{-5}$M GA_3 gave maximum values at each sampling stage, however its value was equalled by that for $N_{90}\times10^{-6}$M Kn at 150 DAP. The control ($N_0\times W_0$) gave significant ~~minimum~~ low values at all samplings. The increase in leaf area due to $N_{90}\times10^{-5}$M GA_3 was 198.29, 221.57, 111.98, 83.97 and 86.33 per cent over the control at 90, 105, 120, 135 and 150 DAP, respectively (Tables 59).

4.5.1.4 Leaf area ratio

Among nitrogen treatments, N_{90} gave maximum value and the value was equalled by that for N_{120} at 90, 135 and 150 DAP, and by that for N_{60} at 105 DAP. The lowest value was recorded for the control (N_0) at all stages. The per cent increase in leaf area ratio resulted from the application of N_{90} was 15.83, 99.71, 15.61, 10.46 and 12.32 over the control at 90, 105, 120, 135 and 150 DAP, respectively.

Regarding phytohormones, 10^{-6}M Kn at 90 DAP and 10^{-4}M GA_3 at 120 DAP gave maximum value. The effect of 10^{-6}M Kn was at par with that of 10^{-5}M Kn at 90 DAP and 10^{-4}M GA_3 was at par with that of 10^{-5}M GA_3 at 120 DAP. Moreover, 10^{-6}M Kn at 105 DAP and 10^{-5}M Kn at 135 and 150 DAP gave significantly higher value in comparison to that for other treatments. On the other hand, the water-sprayed control (W_0) gave the lowest value at all stages. The per cent increase in leaf area ratio

Table 58. Effect of soil-applied nitrogen and leaf-applied phytohormones and of their interaction on root length (cm) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose N kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
N_0	10.94	13.50	12.46	15.30	15.82	13.60	12.60	22.55	22.38	23.05	24.83	21.08
N_{60}	13.28	15.10	13.70	13.83	15.45	14.27	18.75	24.60	22.18	25.50	26.14	22.83
N_{90}	16.57	16.00	15.25	17.01	16.00	16.16	24.70	26.60	23.10	28.27	27.89	26.11
N_{120}	15.49	15.55	15.43	16.10	16.85	15.88	22.10	25.10	24.20	26.00	28.00	24.94
Mean	14.07	15.11	14.21	15.56	16.03		19.54	24.71	22.97	25.71	26.72	
	120 DAP						135 DAP					
N_0	16.89	22.72	20.35	21.79	23.40	21.03	19.35	24.50	24.22	26.70	28.20	24.59
N_{60}	17.63	25.30	26.10	26.87	28.70	24.92	22.80	28.13	29.60	29.43	31.94	28.28
N_{90}	24.25	28.30	28.60	33.23	30.90	29.06	30.18	35.75	33.78	36.95	36.86	34.70
N_{120}	21.09	30.15	29.50	30.50	30.10	28.27	28.57	33.67	33.57	35.76	35.50	33.41
Mean	19.96	26.62	26.14	28.10	28.78		25.23	30.51	30.29	32.96	33.13	
	150 DAP											
N_0	19.00	22.77	22.48	26.95	28.03	23.85						
N_{60}	21.90	26.41	27.91	28.65	31.50	27.27						
N_{90}	29.51	34.00	31.08	36.27	36.10	33.39						
N_{120}	28.47	31.26	30.72	34.00	34.93	31.88						
Mean	24.72	28.61	28.05	31.47	32.64							

	CD at 5%				
	90	105	120	135	150
Nitrogen	0.14	0.15	0.36	0.13	0.24
Phytohormone	0.15	0.17	0.37	0.15	0.27
Interaction	0.31	0.34	0.76	0.30	0.54

Table 59. Effect of soil-applied nitrogen and leaf-applied phytohormones and of their interaction on leaf area (cm^2 $plant^{-1}$) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose N kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
N_0	409	736	759	863	907	735	927	2022	2038	2025	2123	1827
N_{60}	549	809	740	923	990	802	1343	2241	2128	2413	2453	2116
N_{90}	767	1219	797	1121	1068	994	1625	2981	2426	2916	2819	2553
N_{120}	728	996	801	1022	1079	925	1564	2524	2383	2539	2694	2340
Mean	613	940	774	982	1011		1365	2442	2244	2473	2522	
	120 DAP						135 DAP					
N_0	2961	4044	4230	3840	4017	3819	5514	7016	7825	7215	7639	7042
N_{60}	3559	4146	4438	3968	4487	4120	6629	7837	8044	7368	8298	7635
N_{90}	4153	6262	4956	5831	5991	5439	7420	10144	8685	9983	9095	9065
N_{120}	4064	5217	4949	5236	5183	4930	7111	9354	8730	8900	9358	8691
Mean	3685	4917	4643	4719	4920		6669	8588	8321	8366	8598	
	150 DAP											
N_0	5150	6595	7257	7103	7290	6679						
N_{60}	6468	7394	7757	7235	7573	7285						
N_{90}	7111	9596	8336	9577	9179	8760						
N_{120}	6783	9071	8464	8974	9180	8494						
Mean	6378	8164	7954	8222	8305							

CD at 5%					
	90	105	120	135	150
Nitrogen	16.00	17.00	25.00	36.00	28.00
Phytohormone	18.00	19.00	28.00	41.00	31.00
Interaction	32.00	38.00	56.00	81.00	62.00

due to 10^{-5}M GA_3 was 22.62, 28.10, 24.83, 8.01 and 7.29 and due to 10^{-5}M Kn was 33.46, 32.46, 19.53, 15.75 and 16.73 over the control at 90, 105, 120, 135 and 150 DAP respectively.

The interaction effect on this characteristic was found non-significant (Table 60).

4.5.1.5 Specific leaf area

Among nitrogen treatments, N_{90} gave maximum values at all stages, except at 90 DAP at which N_{120} gave maximum value. On the other hand, the control (N_0) gave lowest value at all samplings. The per cent increase in specific leaf area due to N_{90} over the control was 22.28, 11.16, 17.14, 7.66 and 9.33 at 90, 105, 120, 135 and 150 DAP respectively.

With regard to phytohormones, 10^{-5}M Kn gave maximum values at all samplings. However, it was equal to that of 10^{-6}M Kn at 90, 105 DAP and 10^{-4}M GA_3 and 10^{-6}M Kn at 135 and 150 DAP in effect. Moreover, all sprayed phytohormone concentrations were equal in effect at 120 DAP. Significant lowest value was recorded with the water-sprayed control (W_0) at all stages except 90 DAP, at which 10^{-4}M GA_3 gave minimum value. The per cent increase in specific leaf area due to 10^{-5}M Kn over the water-sprayed control was 16.64, 72.89, 25.84, 21.44 and 21.94 per cent at 90, 105, 120, 135 and 150 DAP respectively.

The interaction effect on specific leaf area was non-significant (Table 61).

4.5.1.6 Leaf dry weight

Treatment N_{90} gave significant maximum value at all stages. On the other hand, control (N_0) showed significantly lowest effect. N_{90} gave 12.20, 27.32, 21.48, 19.59 and 19.31 per cent increase in leaf dry weight in comparison with the control at 90, 105, 120, 135 and 150 DAP respectively.

With regard to phytohormones, treatment 10^{-5}M GA_3 gave maximum value at all stages. However, its effect was at par with that of 10^{-5}M Kn at 90 DAP and with that of 10^{-4}M GA_3 at 105 DAP, and with that of 10^{-5}M Kn and 10^{-6}M Kn at 120 DAP. Significant lowest value was registered for the water-sprayed control (W_0) at all stages. The per cent increase in leaf dry weight due to 10^{-5}M Kn over the water-sprayed control was 44.00, 7.81, 5.89, 6.38 and 6.85 at 90, 105, 120, 135 and

Table 60. Effect of soil-applied nitrogen and leaf-applied phytohormones and of their interaction on leaf area ratio ($cm^2\ g^{-1}$) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose N kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
N_0	222.28	320.00	346.58	381.86	379.50	330.04	433.18	584.39	612.01	602.68	608.31	568.11
N_{60}	289.00	321.03	373.74	421.46	394.42	359.93	537.20	645.82	646.81	799.00	648.94	655.55
N_{90}	345.49	438.49	294.09	410.62	422.13	382.16	534.54	716.59	646.93	718.23	722.82	667.82
N_{120}	343.40	392.12	309.27	403.95	405.64	370.88	521.33	648.84	698.83	659.48	703.39	646.37
Mean	300.04	367.91	330.92	404.47	400.42		506.56	648.91	651.14	694.85	670.86	
	120 DAP						135 DAP					
N_0	514.06	677.33	719.39	628.48	573.04	622.46	584.11	588.10	682.21	644.77	698.90	639.62
N_{60}	560.47	638.83	707.81	584.39	680.88	634.48	655.04	632.53	672.01	596.12	694.39	650.15
N_{90}	600.14	794.67	709.01	759.24	882.33	719.62	612.21	729.78	702.67	748.91	738.23	706.36
N_{120}	592.42	719.59	715.17	705.66	720.86	690.74	622.68	721.20	702.90	683.04	732.24	692.41
Mean	566.77	707.60	712.84	669.44	677.46		618.51	667.90	689.95	668.21	715.94	
	150 DAP											
N_0	549.63	554.20	634.35	640.49	668.81	609.51						
N_{60}	640.40	598.22	648.58	598.92	635.32	624.29						
N_{90}	587.68	691.85	677.17	719.53	746.87	684.62						
N_{120}	596.04	702.62	683.13	690.31	720.00	678.36						
Mean	593.44	636.72	660.81	662.31	692.75							

CD at 5%					
	90	105	120	135	150
Nitrogen	21.96	21.39	21.76	23.31	23.61
Phytohormone	24.55	23.91	24.33	26.04	26.40
Interaction	NS	NS	NS	NS	NS

Table 61. Effect of soil-applied nitrogen and leaf-applied phytohormones and of their interaction on specific leaf area ($cm^2\ g^{-1}$) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose N kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
N_0	244.91	272.59	297.15	301.75	308.50	285.08	306.95	555.49	513.35	573.65	588.09	507.51
N_{60}	269.12	278.01	272.06	349.62	353.57	304.48	355.29	554.70	512.77	621.91	602.70	529.47
N_{90}	334.93	397.07	263.91	382.59	366.51	348.60	364.35	623.64	553.88	631.17	646.56	563.92
N_{120}	360.40	329.80	324.29	351.20	383.99	349.94	382.40	551.09	529.56	587.73	598.67	529.89
Mean	302.34	319.37	289.48	346.29	353.64		352.25	571.23	527.39	603.62	609.01	
	120 DAP						135 DAP					
N_0	491.86	584.39	626.67	557.33	564.19	564.89	546.48	652.65	715.27	654.72	691.94	652.21
N_{60}	478.36	563.31	598.11	522.79	593.52	551.22	594.00	644.49	683.43	618.64	708.62	649.84
N_{90}	517.83	721.43	625.76	697.49	746.08	661.72	604.23	730.31	711.30	745.00	720.11	702.19
N_{120}	526.42	651.31	624.87	652.87	631.30	617.35	580.96	709.71	695.06	724.17	703.61	682.70
Mean	503.62	630.11	618.85	607.62	633.78		581.42	684.29	701.27	685.63	706.07	
	150 DAP											
N_0	516.55	615.21	665.17	646.90	662.13	621.19						
N_{60}	582.18	613.61	660.73	619.43	637.46	622.68						
N_{90}	580.96	693.35	676.07	716.30	729.07	679.15						
N_{120}	556.90	683.57	678.21	731.97	698.63	669.86						
Mean	559.15	651.44	670.05	678.65	681.82							

	CD at 5%				
	90	105	120	135	150
Nitrogen	24.24	18.61	22.40	18.89	18.80
Phytohormone	27.10	20.80	25.04	21.12	21.03
Interaction	NS	NS	NS	NS	NS

150 DAP, respectively. Moreover, treatment 10^{-5}M GA_3 gave 45.00, 10.94, 6.03, 9.26 and 7.58 per cent higher values over the water-sprayed control at 90, 105, 120, 135 and 150 DAP, respectively.

Regarding interaction effect, $N_{90}\times10^{-5}$M GA_3 gave significant maximum value at 105, 120, 135 and 150 DAP. However at 90 DAP, its maximum value was equalled by those for $N_{120}\times10^{-5}$M GA_3 and $N_{90}\times10^{-4}$M GA_3. ~~Significant~~ The lowest value was given by the control (N_0W_0) at all samplings. The per cent increase in leaf dry weight resulted from the application of $N_{90}\times10^{-5}$M GA_3 over the control was 83.83, 58.28, 44.19, 37.66 and 38.82 at 90, 105, 120, 135 and 150 DAP, respectively (Table 62).

4.5.1.7 Specific leaf weight

Maximum specific leaf weight was recorded with the control (N_0) at all stages, however its value was at par with that for N_{60} at 120, 135 and 150 DAP. On the other hand, N_{90} and N_{120} being at par gave minimum value at all stages. The per cent decrease in specific leaf weight due to N_{90} over the control (N_0) was 20.48, 12.43, 18.18, 8.39 and 10.14 at 90, 105, 120, 135 and 150 DAP, respectively.

Among spray treatments, the water-sprayed control (W_0) gave maximum value at all stages, except 90 DAP, at which 10^{-4}M GA_3 gave maximum value, and the value was at par with water-sprayed control (W_0) in effect. Treatment 10^{-5}M Kn gave minimum value at all samplings, but at 90 DAP, it was equal in effect to 10^{-6}M Kn, and at 105 DAP also to 10^{-5}M GA_3. At 120, 135 and 150 DAP, 10^{-5}M Kn, 10^{-6}M Kn, 10^{-5}M GA_3 and 10^{-4}M GA_3 being at par showed equal effect. The per cent decrease in specific leaf weight due to 10^{-5}M Kn in comparison with the water-sprayed control was 18.95, 73.78, 25.16, 21.13 and 22.49 at 90, 105, 120, 135 and 150 DAP, respectively.

The interaction effect of nitrogen and phytohormones on specific leaf weight was found to be non-significant (Table 63).

4.5.1.8 Stem dry weight

Treatment N_{90} gave significant maximum value at all stages. The value recorded for the control (N_0) was significantly lowest at each stage of sampling. Treatment N_{90} gave 21.03, 19.62, 18.70, 18.45 and 18.01 per cent increase in stem dry weight over the control at 90, 105, 120, 135 and 150 DAP, respectively.

Table 62. Effect of soil-applied nitrogen and leaf-applied phytohormones and of their interaction on leaf dry weight (g plant^{-1}) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose N kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
N_0	1.67	2.70	2.55	2.86	2.94	2.54	3.02	3.64	3.97	3.53	3.61	3.55
N_{60}	2.04	2.91	2.72	2.64	2.84	2.62	3.78	4.04	4.15	3.88	4.07	3.98
N_{90}	2.29	3.07	3.02	2.93	2.93	2.85	4.46	4.78	4.38	4.62	4.36	4.52
N_{120}	2.02	3.02	2.47	2.91	2.81	2.65	4.09	4.58	4.50	4.32	4.50	4.40
Mean	2.00	2.92	2.69	2.84	2.88		3.84	4.26	4.25	4.09	4.14	
	120 DAP						135 DAP					
N_0	6.02	6.92	6.75	6.89	7.12	6.74	10.09	10.75	10.94	11.02	11.04	10.77
N_{60}	7.44	7.36	7.42	7.59	7.56	7.47	11.16	12.16	11.77	11.91	11.71	11.74
N_{90}	8.02	8.68	7.92	8.36	8.03	8.20	12.28	13.89	12.21	13.40	12.63	12.88
N_{120}	7.72	8.01	7.72	8.02	8.21	7.94	12.24	13.18	12.56	12.29	13.30	12.71
Mean	7.30	7.74	7.45	7.72	7.73		11.44	12.50	11.87	12.16	12.17	
	150 DAP											
N_0	9.97	10.72	10.91	10.98	11.01	10.72						
N_{60}	11.11	12.05	11.74	11.68	11.88	11.69						
N_{90}	12.24	13.84	12.33	13.37	12.59	12.87						
N_{120}	12.18	13.27	12.48	12.26	13.14	12.67						
Mean	11.38	12.47	11.87	12.07	12.16							

	CD at 5%				
	90	105	120	135	150
Nitrogen	0.03	0.04	0.10	0.13	0.14
Phytohormone	0.04	0.05	0.12	0.15	0.15
Interaction	0.07	0.10	0.24	0.30	0.31

Table 63. Effect of soil-applied nitrogen and leaf-applied phytohormones and of their interaction on specific leaf weight (mg cm^{-2}) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose N kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
N_0	4.08	3.67	3.36	3.31	3.24	3.53	3.26	1.80	1.95	1.70	1.70	2.08
N_{60}	3.71	3.60	3.68	2.86	2.83	3.34	2.81	1.80	1.95	1.61	1.66	1.97
N_{90}	2.98	2.52	3.79	2.61	2.74	2.93	2.74	1.60	1.80	1.58	1.55	1.85
N_{120}	2.77	3.03	3.08	2.85	2.60	2.87	2.61	1.81	1.89	1.70	1.67	1.94
Mean	3.39	3.21	3.48	2.91	2.85		2.85	1.75	1.90	1.65	1.64	
	120 DAP						135 DAP					
N_0	2.03	1.71	1.59	1.79	1.77	1.78	1.83	1.53	1.40	1.53	1.45	1.55
N_{60}	2.09	1.77	1.67	1.91	1.68	1.82	1.68	1.55	1.46	1.62	1.41	1.54
N_{90}	1.93	1.39	1.60	1.43	1.34	1.54	1.65	1.37	1.41	1.34	1.39	1.43
N_{120}	1.90	1.53	1.56	1.53	1.58	1.62	1.72	1.41	1.44	1.38	1.42	1.47
Mean	1.99	1.60	1.61	1.67	1.59		1.72	1.47	1.43	1.47	1.42	
	150 DAP											
N_0	1.94	1.63	1.50	1.55	1.51	1.63						
N_{60}	1.72	1.63	1.51	1.61	1.57	1.61						
N_{90}	1.72	1.44	1.48	1.40	1.37	1.48						
N_{120}	1.80	1.46	1.47	1.37	1.43	1.51						
Mean	1.80	1.54	1.49	1.48	1.47							

	CD at 5%				
	90	105	120	135	150
Nitrogen	0.17	0.10	0.11	0.06	0.07
Phytohormone	0.19	0.12	0.12	0.07	0.08
Interaction	NS	NS	NS	NS	NS

Regarding phytohormones, treatment 10^{-5}M GA_3 at 90, 135 and 150 DAP and 10^{-5}M Kn at 105 and 120 DAP gave maximum value. However, the value recorded for 10^{-5}M GA_3 was equal to that for 10^{-5}M Kn at 90 DAP. Treatments 10^{-5}M Kn and 10^{-6}M at 120 DAP were equally effective. The significant minimum value was recorded for the water-sprayed control (W_0) at all samplings. In comparison with the control the increase in stem fresh weight at 90, 105, 120, 135 and 150 DAP due to 10^{-5}M GA_3 was 29.59, 34.46, 4.33, 17.43 and 17.60 per cent and due to 10^{-5}M Kn was 28.57, 40.45, 7.43, 13.82 and 13.31 per cent respectively.

With regard to interactions, $N_{90}\times10^{-5}$M GA_3 gave maximum value at all stages. At 90 DAP, its effect was equalled by that of $N_{90}\times10^{-6}$M Kn, $N_{90}\times10^{-4}$M GA_3, $N_{120}\times10^{-5}$M Kn and at 105 DAP, by that of $N_{90}\times10^{-6}$M Kn. The effect of the control ($N_0\times W_0$) was significantly lowest at all stages. The per cent increase in stem dry weight resulted from the application of $N_{90}\times10^{-5}$M GA_3 over the control was 75.95, 93.49, 38.45, 47.24 and 47.87 at 90, 105, 120, 135 and 150 DAP respectively (Table 64).

4.5.1.9 Aboveground plant dry weight

Among nitrogen treatments, N_{90} produced significantly highest plant dry matter in comparison with other treatments at all stages, except 90 DAP, at which the value was equalled by that for N_{120}. Significant lowest value was recorded for the control (N_0) at each sampling stage. Treatment N_{90} gave 12.37, 23.88, 20.54, 18.57 and 18.65 per cent more aboveground plant dry weight than the control at 90, 105, 120, 135 and 150 DAP respectively.

Pertaining to the effect of phytohormones, 10^{-5}M Kn gave maximum value at 90, 105 and 120 DAP but at 135 and 150 DAP, the maximum value was given by 10^{-5}M GA_3. However, the effect of 10^{-5}M Kn was equal to that of 10^{-5}M GA_3 and 10^{-6}M Kn at 90 and 120 DAP, and to those of 10^{-5}M GA_3 and 10^{-4}M GA_3 at 105 DAP. The effect of the water-sprayed control (W_0) was significantly minimum at all samplings. In comparison with the control the per cent increase in aboveground plant dry weight due to 10^{-5}M Kn was 37.40, 21.38, 6.61, 10.17 and 10.13 and due to 10^{-5}M GA_3 was 34.86, 21.23, 5.16, 13.04 and 12.16 at 90, 105, 120, 135 and 150 DAP respectively.

Table 64. Effect of soil-applied nitrogen and leaf-applied phytohormones and of their interaction on stem dry weight (g) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose N kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
N_0	1.58	2.30	2.19	2.26	2.38	2.14	2.15	3.33	3.29	3.36	3.49	3.12
N_{60}	1.90	2.52	1.98	2.18	2.52	2.22	2.49	3.46	3.47	3.02	3.78	3.24
N_{90}	2.22	2.78	2.71	2.73	2.53	2.59	3.04	4.16	3.75	4.06	3.90	3.78
N_{120}	2.12	2.54	2.59	2.54	2.66	2.49	3.00	3.41	3.89	3.85	3.83	3.60
Mean	1.96	2.54	2.37	2.43	2.52		2.67	3.59	3.60	3.57	3.75	
	120 DAP						135 DAP					
N_0	5.69	5.88	6.04	6.11	7.02	6.15	9.44	11.93	10.93	10.93	11.19	10.99
N_{60}	6.35	6.27	6.49	6.44	6.78	6.47	10.13	11.99	11.96	11.96	12.11	11.71
N_{90}	6.93	7.88	7.22	7.68	6.78	7.30	12.13	13.03	13.33	13.33	12.76	13.03
N_{120}	6.86	6.93	7.24	7.31	7.19	7.11	11.42	12.94	12.78	12.78	13.03	12.52
Mean	6.46	6.74	6.75	6.89	6.94		10.78	12.36	12.25	12.25	12.27	
	150 DAP											
N_0	9.38	11.90	11.44	10.90	11.09	10.94						
N_{60}	10.10	12.36	11.69	11.93	12.08	11.69						
N_{90}	12.10	13.87	12.78	13.31	12.51	12.91						
N_{120}	11.38	12.39	12.91	12.30	13.00	12.40						
Mean	10.74	12.63	12.27	12.11	12.17							

CD at 5%					
	90	105	120	135	150
Nitrogen	0.07	0.05	0.07	0.04	0.05
Phytohormone	0.07	0.05	0.08	0.05	0.06
Interaction	0.15	0.10	0.16	0.09	0.12

Regarding interactions, $N_{90}\times10^{-5}$M GA_3 gave maximum value at all samplings, but its effect was at par with that of $N_{90}\times10^{-4}$M GA_3, $N_{120}\times10^{-5}$M GA_3 and $N_{90}\times10^{-6}$M Kn at 90 DAP, and with those of $N_{90}\times10^{-6}$M Kn at 105, 120 and 150 DAP. Significant minimum value was given by the control (N_0W_0). Treatment $N_{90}\times10^{-5}$M GA_3 gave 78.59, 73.11, 40.81, 42.14 and 43.31 per cent aboveground plant dry matter than the control at 90, 105, 120, 135 and 150 DAP, respectively (Table 65).

4.5.1.10 Underground plant fresh weight

Maximum value was recorded for N_{90}, and minimum for the control (N_0) at all sampling stages. The per cent increase in underground plant fresh weight due to N_{90} over the control was 32.03, 27.54, 19.64, 23.34 and 24.10 at 90, 105, 120, 135 and 150 DAP, respectively.

Among spray treatments, 10^{-5}M Kn gave maximum value, however its effect was equalled by that of 10^{-6}M Kn at 90, 105, 135 and 150 DAP. The minimum value was given by the water-sprayed control (W_0) at all stages. The per cent increase in underground plant fresh weight due to 10^{-5}M Kn over the water-sprayed control was 31.80, 70.39, 54.48, 47.87 and 49.75 at 90, 105, 120, 135 and 150 DAP, respectively.

Regarding interaction effect, $N_{90}\times10^{-6}$M Kn gave significant maximum value at 90, 105, 120 and 150 DAP, however at 135 DAP, its effect was at par with those of $N_{90}\times10^{-5}$M GA_3 and $N_{120}\times10^{-5}$M Kn. Significant minimum value was recorded for the control ($N_0\times W_0$) at all samplings. Treatment $N_{90}\times10^{-5}$M GA_3 gave 120.41, 170.58, 83.40, 91.60 and 93.19 per cent more underground plant fresh matter than the control at 90, 105, 120, 135 and 150 DAP, respectively (Table 66).

4.5.1.11 Underground plant dry weight

Significant maximum and minimum values were given by N_{90} and control (N_0) respectively at all samplings. Treatment N_{90} resulted in 31.75, 27.41, 19.64, 23.37 and 26.28 per cent increase in underground plant dry weight over the control at 90, 105, 120, 135 and 150 DAP, respectively.

Regarding phytohormones effect, 10^{-5}M Kn gave maximum value at all stages, however its value was equalled by that for 10^{-6}M Kn at 90, 105, 135 and 150 DAP. ~~Significant~~ The lowest value was given by the water-sprayed control (W_0) at all stages, except 90 DAP, at which 10^{-4}M GA_3 showed a significantly lowest effect. The per cent

Table 65. Effect of soil-applied nitrogen and leaf-applied phytohormones and of their interaction on dry weight (g plant^{-1}) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose N kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
N_0	3.27	4.90	4.85	5.12	5.32	4.69	5.17	7.07	7.30	6.89	7.10	6.70
N_{60}	3.94	4.90	5.24	4.83	5.32	4.70	6.26	7.50	7.62	6.90	7.85	7.22
N_{90}	4.38	5.84	5.73	5.66	5.47	5.27	7.49	8.95	8.13	8.68	8.27	8.30
N_{120}	4.14	5.56	5.06	5.44	5.47	5.19	7.09	7.98	8.39	8.17	8.34	7.99
Mean	3.93	5.30	5.22	5.26	5.40		6.50	7.88	7.86	7.66	7.89	
	120 DAP						135 DAP					
N_0	11.76	12.81	12.81	13.00	14.13	12.90	19.53	22.68	22.87	21.97	22.23	21.86
N_{60}	13.79	13.62	13.90	14.03	14.36	13.94	21.27	24.47	24.16	23.67	24.02	23.52
N_{90}	14.95	16.56	15.14	16.27	14.82	15.55	24.48	27.76	25.23	26.73	25.39	25.92
N_{120}	14.58	14.93	14.96	15.35	15.41	15.05	23.65	25.60	25.50	25.07	26.32	25.23
Mean	13.77	14.48	14.20	14.66	14.68		22.23	25.13	24.44	24.36	24.49	
	150 DAP											
N_0	19.35	22.16	22.81	21.88	22.10	21.66						
N_{60}	21.21	24.01	24.10	23.61	23.96	23.37						
N_{90}	24.34	27.73	24.66	26.68	25.11	25.70						
N_{120}	23.58	25.35	25.39	24.56	26.27	25.03						
Mean	22.12	24.81	24.24	24.18	24.36							

	CD at 5%				
	90	105	120	135	150
Nitrogen	0.15	0.13	0.13	0.26	0.17
Phytohormone	0.16	0.15	0.14	0.28	0.19
Interaction	0.33	0.30	0.29	0.59	0.38

Table 66. Effect of soil-applied nitrogen and leaf-applied phytohormones and of their interaction on plant fresh weight (g plant^{-1}) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose N kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
N_0	3.87	5.17	4.17	7.33	7.73	5.65	5.37	7.57	6.47	12.22	12.70	8.86
N_{60}	5.57	5.13	4.12	7.35	7.58	5.95	7.57	8.32	9.60	12.28	12.40	10.03
N_{90}	7.28	7.63	5.87	8.53	8.00	7.46	9.03	10.63	8.90	14.53	13.40	11.30
N_{120}	6.80	7.13	4.53	7.60	7.70	6.75	8.83	9.40	7.97	13.17	13.98	10.67
Mean	5.88	6.27	4.67	7.70	7.75		7.70	8.98	8.23	13.05	13.12	
	120 DAP						135 DAP					
N_0	11.63	13.18	12.90	18.83	19.07	15.12	14.77	15.93	15.67	26.57	27.10	20.01
N_{60}	12.48	16.58	11.60	18.27	19.17	15.62	17.97	16.75	21.00	27.10	27.53	22.07
N_{90}	13.43	20.87	14.82	21.33	20.00	18.09	21.27	28.00	18.60	28.30	27.27	24.69
N_{120}	13.37	18.57	13.83	17.80	20.37	16.79	20.13	24.60	20.60	27.20	27.73	24.05
Mean	12.72	17.30	13.19	19.06	19.65		18.53	21.32	18.97	27.29	27.40	
	150 DAP											
N_0	14.53	15.67	15.43	26.30	26.80	19.75						
N_{60}	17.43	16.50	20.63	26.77	27.27	21.72						
N_{90}	20.97	28.07	18.37	28.07	27.10	24.51						
N_{120}	19.60	24.33	20.17	27.00	27.42	23.70						
Mean	18.13	21.14	18.65	27.03	27.15							

CD at 5%					
	90	105	120	135	150
Nitrogen	0.19	0.21	0.17	0.26	0.21
Phytohormone	0.21	0.24	0.20	0.29	0.24
Interaction	0.43	0.47	0.39	0.57	0.48

increase in underground plant dry weight resulted from the application of 10^{-5}M Kn over the control was 31.30, 70.76, 54.42, 47.81 and 46.90 at 90, 105, 120, 135 and 150 DAP respectively.

Regarding interactions, $N_{90}\times10^{-6}$M Kn gave maximum value for underground plant dry weight at all growth stages, but at 135 DAP, its effect was equalled by that of $N_{90}\times10^{-5}$M GA_3. The effect of control ($N_0\times W_0$) was lowest at all stages. The increase in underground plant dry weight due to $N_{90}\times10^{-6}$M Kn over the control was 120.93, 176.47, 83.72, 91.77 and 93.19 per cent at 90, 105, 120, 135 and 150 DAP respectively (Table 67).

4.5.2 Physiological characteristic

4.5.2.1 Photosynthetic characteristics

Effect of soil-applied nitrogen and leaf-applied phytohormones alone as well as of their interaction on photosynthetic characters studied was significant at all stages (Table 68-72).

4.5.2.1.1 Chlorophyll content

Maximum value was recorded for N_{90} at all stages. Minimum significant value was recorded for the control (N_0). The increase in chlorophyll content due to N_{90} over the control was 8.70, 23.81, 23.60, 16.81 and 19.73 per cent at 90, 105, 120, 135 and 150 DAP respectively.

Among phytohormone treatments, 10^{-5}M GA_3 gave significant maximum value at all stages, except 90 DAP, at which its value was equalled by that for 10^{-5}M Kn. On the other hand significant lowest values were noted for the water-sprayed control (W_0). Application of treatment 10^{-5}M GA_3 resulted in 8.51, 11.61, 9.33, 12.55 and 11.26 per cent increase in chlorophyll content over water-sprayed control at 90, 105, 120, 135 and 150 DAP respectively.

With regard to interaction effect, $N_{90}\times10^{-5}$M GA_3 gave maximum value at all stages. However, it was equal to $N_{90}\times10^{-6}$M Kn at 90, 120 and 150 DAP in effect. Significant minimum value was recorded for control ($N_0\times W_0$) at all samplings. The per cent increase in chlorophyll content by $N_{90}\times10^{-5}$M GA_3 over the control at 90, 105, 120, 135 and 150 DAP was 46.36, 45.38, 43.75, 37.44 and 42.86 per cent, respectively (Table 68).

Table 67. Effect of soil-applied nitrogen and leaf-applied phytohormones and of their interaction on underground plant dry weight (g plant^{-1}) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose N kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
N_0	0.86	1.15	0.93	1.63	1.72	1.26	1.19	1.68	1.44	2.72	2.82	1.97
N_{60}	1.24	1.14	0.92	1.63	1.68	1.32	1.68	1.85	2.13	2.73	2.76	2.23
N_{90}	1.62	1.70	1.30	1.90	1.78	1.66	2.01	2.36	1.98	3.29	2.98	2.51
N_{120}	1.51	1.58	1.01	1.69	1.71	1.50	1.96	2.09	1.77	2.93	3.12	2.37
Mean	1.31	1.39	1.04	1.71	1.72		1.71	1.99	1.83	2.92	2.92	
	120 DAP						135 DAP					
N_0	2.58	2.93	2.87	4.18	4.24	3.36	3.28	3.54	3.48	5.90	6.02	4.44
N_{60}	2.77	3.68	2.59	4.06	4.26	3.47	3.99	3.72	3.72	6.02	6.12	4.90
N_{90}	2.98	4.64	3.29	4.74	4.44	4.02	4.73	6.22	4.13	6.31	6.06	5.49
N_{120}	2.97	4.12	3.07	3.96	4.53	3.73	4.47	5.47	4.58	6.04	6.16	5.33
Mean	2.83	3.84	2.95	4.24	4.37		4.10	4.97	3.98	6.10	6.06	
	150 DAP											
N_0	3.23	3.48	3.43	5.62	5.73	4.30						
N_{60}	3.87	3.67	3.59	5.73	5.84	4.54						
N_{90}	4.66	6.14	4.08	6.24	6.02	5.43						
N_{120}	4.36	5.43	4.48	5.78	6.09	5.27						
Mean	4.03	4.65	3.90	5.84	5.92							

CD at 5%					
	90	105	120	135	150
Nitrogen	0.08	0.05	0.04	0.05	0.07
Phytohormone	0.09	0.05	0.04	0.06	0.08
Interaction	0.17	0.11	0.09	0.11	0.16

Table 68. Effect of soil-applied nitrogen and leaf-applied phytohormones and of their interaction on chlorophyll content (mg g^{-1} fresh weight) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose N kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
N_0	1.10	1.46	1.36	1.49	1.50	1.38	1.30	1.57	1.49	1.48	1.52	1.47
N_{60}	1.20	1.49	1.40	1.49	1.54	1.42	1.50	1.65	1.60	1.54	1.60	1.58
N_{90}	1.28	1.61	1.47	1.59	1.54	1.50	1.77	1.89	1.74	1.85	1.83	1.82
N_{120}	1.26	1.55	1.42	1.44	1.49	1.43	1.63	1.79	1.82	1.73	1.79	1.75
Mean	1.21	1.53	1.41	1.50	1.52		1.55	1.73	1.66	1.65	1.68	
	120 DAP						135 DAP					
N_0	1.60	1.88	1.78	1.82	1.83	1.78	2.11	2.48	2.39	2.30	2.34	2.32
N_{60}	1.97	2.05	1.96	2.00	2.01	2.00	2.33	2.58	2.50	2.49	2.62	2.50
N_{90}	2.12	2.30	2.09	2.27	2.22	2.20	2.59	2.90	2.60	2.80	2.70	2.71
N_{120}	2.04	2.21	2.04	2.07	2.17	2.11	2.56	2.78	2.62	2.68	2.75	2.68
Mean	1.93	2.11	1.97	2.04	2.06		2.39	2.69	2.52	2.57	2.60	
	150 DAP											
N_0	1.96	2.25	2.29	2.26	2.28	2.23						
N_{60}	2.11	2.53	2.46	2.30	2.45	2.37						
N_{90}	2.53	2.80	2.51	2.76	2.65	2.67						
N_{120}	2.51	2.70	2.57	2.45	2.58	2.56						
Mean	2.31	2.57	2.46	2.45	2.49							

	CD at 5%				
	90	105	120	135	150
Nitrogen	0.01	0.02	0.02	0.02	0.03
Phytohormone	0.01	0.02	0.02	0.03	0.04
Interaction	0.02	0.04	0.04	0.05	0.07

4.5.2.1.2 Chlorophyll harvest

Treatment N_{90} and the control (N_0) gave maximum and minimum values respectively at each growth stage. Treatment N_{90} gave 44.96, 70.71, 75.68, 50.12 and 58.04 per cent increase in chlorophyll harvest over the control at 90, 105, 120, 135 and 150 DAP respectively.

As far as phytohormone effect was concerned, 10^{-5}M Kn at 90 DAP and 10^{-5}M GA_3 at 120, 135 and 150 DAP gave significantly maximum values. However, at 105 DAP, the value given by 10^{-5}M Kn was equal to that for 10^{-5}M GA_3. On the other hand, significant minimum value was recorded for the water-sprayed control (W_0). The increase in chlorophyll harvest due to 10^{-5}M Kn was 96.68, 100.33, 42.12, 39.17 and 41.58 per cent and due to 10^{-5}M GA_3 was 87.10, 99.06, 45.74, 44.58 and 45.81 per cent over the water-sprayed control at 90, 105, 120, 135 and 150 DAP respectively.

Regarding interaction effect, $N_{90}\times10^{-5}$M GA_3 gave significant maximum value at all stages. The value recorded for the control ($N_0\times W_0$) was significantly lowest at all stages. The increase in chlorophyll harvest due to $N_{90}\times10^{-5}$M GA_3 over the control was 336.22, 367.55, 204.01, 152.86 and 173.79 per cent at 90, 105, 120, 135 and 150 DAP respectively (Table 69).

4.5.2.1.3 Photosynthetic rate

Treatment N_{90} gave significant maximum value at each stage of sampling. On the other hand, significant minimum value was noted for the control (N_0). The increase in rate of photosynthesis by N_{90} over the control at 90, 105, 120, 135 and 150 DAP, was 21.81, 18.50, 20.05, 15.19 and 15.17 per cent respectively.

Pertaining to phytohormone treatments, 10^{-5}M Kn at 90, 105 and 120 DAP and 10^{-5}M GA_3 at 135 and 150 DAP gave maximum value. Treatments 10^{-5}M Kn and 10^{-6}M Kn were equally effective at 105 and 120 DAP. Significant minimum value was recorded for the water-sprayed control (W_0) at all stages. In comparison with the water-sprayed control, increase in rate of photosynthesis due to 10^{-5}M Kn was 31.81, 15.19 and 4.76, 7.66 and 7.43 per cent and due to 10^{-5}M GA_3 was 31.81, 15.07, 4.13, 9.67 and 6.59 per cent at 90, 105, 120, 135 and 150 DAP respectively.

Table 69. Effect of soil-applied nitrogen and leaf-applied phytohormones and of their interaction on chlorophyll harvest (mg . cm^2) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose N kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
N_0	450	1074	1032	1286	1361	1041	1205	3174	3037	2997	3227	2728
N_{60}	659	1205	1036	1375	1525	1160	2015	3698	3405	3716	3925	3352
N_{90}	982	1963	1172	1782	1645	1509	2876	5634	4221	5395	5159	4657
N_{120}	917	1544	1137	1472	1608	1336	2549	4518	4337	4393	4822	4124
Mean	752	1407	1094	1479	1479		2138	4256	3750	4125	4283	
	120 DAP						135 DAP					
N_0	4737	7603	7529	6989	7351	6842	11634	17400	18702	16594	17875	16441
N_{60}	7011	8499	8698	7936	9019	8233	15445	20219	20110	18346	21741	19172
N_{90}	8804	14401	10359	13237	13300	12020	19069	29418	22407	27952	24557	24681
N_{120}	8210	11529	10096	10839	11247	10400	18204	26004	22873	23852	25735	23334
Mean	7210	10508	9170	9750	10247		16088	23260	21023	21686	22477	
	150 DAP											
N_0	10094	14839	16618	16053	16621	14845				CD at 5%		
N_{60}	13647	18707	19082	16682	18554	17478			90	105	120	135	150
N_{90}	17991	27636	20923	26432	24324	23461	Nitrogen		19	71	79	105	115
N_{120}	17025	24492	21752	21986	23684	21788	Phytohormone		22	80	88	117	128
Mean	14689	21418	19594	20288	20796		Interaction		44	153	176	235	252

Regarding interaction effect, $N_{90}\times10^{-5}$M GA_3 gave maximum value at each stage, and the value was equalled by that for $N_{90}\times10^{-4}$M GA_3 and $N_{90}\times10^{-6}$M Kn at 90 DAP and by those for $N_{90}\times10^{-6}$M Kn at 105, 120 and 135 DAP. On the other hand, significant minimum value was given by the control ($N_0\times W_0$). The increase in rate of photosynthesis resulted from the application of $N_{90}\times10^{-5}$M GA_3 was 60.13, 35.79, 35.62, 27.90 and 26.67 per cent over the control at 90, 105, 120, 135 and 150 DAP, respectively (Table 70).

4.5.2.1.4 Stomatal conductance

Among treatments of nitrogen, maximum and minimum value was given by N_{90} and control (N_0), respectively. Treatment N_{90} gave 11.20, 9.33, 9.83, 6.57 and 6.34 per cent increase in stomatal conductance in comparison with the control at 90, 105, 120, 135 and 150 DAP, respectively.

Regarding phytohormones, 10^{-5}M Kn at 90, 105 and 120 DAP and 10^{-5}M GA_3 at 135 and 150 DAP gave maximum value for stomatal conductance. The water-sprayed control (W_0) gave significant lowest values at all samplings. The increase in stomatal conductance resulted from application of 10^{-5}M Kn was 18.53, 7.33, 3.36, 3.00 and 2.78 per cent and, from 10^{-5}M GA_3 was 15.52, 7.00, 1.68, 3.75 and 3.54 per cent over the water-sprayed control at 90, 105, 120, 135 and 150 DAP, respectively.

Regarding interaction effect, $N_{90}\times10^{-5}$M GA_3 gave maximum value and the value was equalled by that for $N_{90}\times10^{-4}$M GA_3 at 90 DAP and by that for $N_{90}\times10^{-6}$M Kn at 105, 120, 135 and 150 DAP. Significant minimum value was recorded for the control ($N_0\times W_0$) at all stages. The increase in stomatal conductance due to $N_{90}\times10^{-5}$M GA_3 over the control was 29.78, 16.21, 14.79, 10.03 and 9.82 per cent at 90, 105, 120, 135 and 150 DAP, respectively (Table 71).

4.5.2.1.5 Photosynthetic water use efficiency

Of nitrogen treatments, N_{90} and the control (N_0) gave maximum and minimum values, respectively. Treatment N_{90} gave 9.38, 8.60, 10.84, 8.19 and 8.46 per cent increase in photosynthetic water use efficiency over the control at 90, 105, 120, 135 and 150 DAP, respectively.

Table 70. Effect of soil-applied nitrogen and leaf-applied phytohormones and of their interaction on photosynthetic rate (μ mol CO_2 $m^{-2}s^{-1}$) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose N kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
N_0	9.28	10.89	10.61	11.97	12.95	11.14	14.92	19.24	17.10	15.70	16.85	16.16
N_{60}	9.41	11.26	12.27	10.29	12.62	11.17	15.55	17.67	17.86	15.77	18.17	17.00
N_{90}	10.10	14.86	14.82	14.44	13.65	13.57	17.37	20.26	18.76	20.01	19.37	19.15
N_{120}	9.79	13.85	11.68	13.37	13.75	12.49	16.39	19.75	18.40	19.00	19.59	18.63
Mean	9.65	12.72	12.35	12.52	13.24		16.06	18.48	18.03	17.62	18.50	
	120 DAP						135 DAP					
N_0	20.86	22.04	22.10	22.45	24.41	22.44	28.53	31.26	31.66	30.67	30.91	30.61
N_{60}	23.06	22.69	23.71	23.82	24.70	23.40	30.20	33.60	33.18	32.42	32.82	32.44
N_{90}	26.22	28.29	27.20	27.95	25.49	26.94	34.06	36.50	34.69	36.20	34.85	35.26
N_{120}	24.78	25.82	26.41	27.28	27.60	26.55	32.06	35.55	35.03	34.33	35.85	34.56
Mean	23.73	24.71	24.86	25.34	25.55		31.21	34.23	33.64	33.40	33.60	
	150 DAP											
N_0	28.20	30.14	30.46	29.38	29.75	29.59						
N_{60}	29.02	32.20	31.94	31.54	31.24	31.19						
N_{90}	32.54	35.72	33.37	35.03	33.72	34.08						
N_{120}	30.84	34.11	34.44	32.98	34.86	33.45						
Mean	30.15	33.04	32.55	32.23	32.39							

	CD at 5%				
	90	105	120	135	150
Nitrogen	0.19	0.19	0.24	0.21	0.15
Phytohormone	0.21	0.21	0.26	0.13	0.16
Interaction	0.42	0.42	0.53	0.48	0.33

Table 71. Effect of soil-applied nitrogen and leaf-applied phytohormones and of their interaction on stomatal conductance (mol $m^{-2}s^{-1}$) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose N kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
N_0	0.225	0.246	0.245	0.262	0.271	0.250	0.290	0.300	0.309	0.297	0.306	0.300
N_{60}	0.228	0.253	0.265	0.241	0.269	0.251	0.295	0.315	0.316	0.298	0.319	0.309
N_{90}	0.240	0.292	0.292	0.286	0.279	0.278	0.312	0.337	0.325	0.335	0.330	0.328
N_{120}	0.236	0.281	0.259	0.275	0.280	0.266	0.302	0.333	0.321	0.327	0.332	0.323
Mean	0.232	0.268	0.265	0.266	0.275		0.300	0.321	0.318	0.314	0.322	
	120 DAP						135 DAP					
N_0	0.338	0.343	0.343	0.347	0.360	0.346	0.389	0.398	0.400	0.396	0.396	0.396
N_{60}	0.354	0.350	0.358	0.359	0.361	0.356	0.393	0.412	0.410	0.405	0.408	0.406
N_{90}	0.374	0.388	0.381	0.386	0.370	0.380	0.416	0.428	0.418	0.427	0.419	0.422
N_{120}	0.362	0.372	0.375	0.382	0.384	0.375	0.402	0.423	0.421	0.416	0.425	0.417
Mean	0.357	0.363	0.364	0.369	0.369		0.400	0.415	0.412	0.411	0.412	
	150 DAP											
N_0	0.387	0.395	0.396	0.391	0.393	0.392						
N_{60}	0.390	0.406	0.404	0.400	0.402	0.400						
N_{90}	0.410	0.425	0.412	0.422	0.414	0.417						
N_{120}	0.399	0.416	0.418	0.411	0.420	0.413						
Mean	0.396	0.410	0.408	0.406	0.407							

	CD at 5%				
	90	105	120	135	150
Nitrogen	0.001	0.001	0.001	0.001	0.001
Phytohormone	0.001	0.001	0.001	0.001	0.001
Interaction	0.002	0.003	0.002	0.002	0.003

Among phytohormones, 10^{-5}M Kn at 90 and 120 DAP and 10^{-5}M GA_3 at 135 and 150 DAP gave significant maximum value. However, at 105 DAP 10^{-5}M Kn and 10^{-4}M GA_3 were equally effective. On the other hand, the water-sprayed control (W_0) gave significant minimum value at each growth stage. The per cent increase in photosynthetic water use efficiency resulted from the application of 10^{-5}M Kn was 15.99, 7.17, 4.36, 4.57 and 4.82 and from the application of 10^{-5}M GA_3 was 13.78, 6.33, 14.49, 3.52 and 5.83 per cent over water-sprayed control at 90, 105, 120, 135 and 150 DAP, respectively.

Regarding interaction effect, $N_{90}\times10^{-5}$M GA_3 gave significant maximum value at 120, 135 and 150 DAP, however its maximum value was equalled by that for $N_{90}\times10^{-4}$M GA_3 at 90 DAP and by that for $N_{90}\times10^{-6}$M Kn at 105 DAP. Minimum value was recorded for the control ($N_{0\times}W_0$) at all stages.

In comparison to the control $N_{90}\times10^{-5}$M GA_3 gave 23.40, 16.85, 18.13, 16.28 and 15.34 per cent higher value for photosynthetic water use efficiency at 90, 105, 120, 135 and 150 DAP, respectively (Table 72).

4.5.2.2 Nutrient contents in plant

The effect of soil-applied nitrogen on nitrogen content was found significant at all stages. However, effect of leaf-applied phytohormones and their interaction with soil-applied nitrogen on nitrogen, phosphorus and potassium content was non-significant at all stages (Tables 73-75).

4.5.2.2.1 Nitrogen content

Significant maximum value was registered for N_{90} at all stages. Effect of the control (N_0) was lowest at all samplings. The per cent increase in nitrogen content due to N_{90} over the control was 30.92, 35.82, 38.22, 26.87 and 24.84 at 90, 105, 120, 135 and 150 DAP, respectively.

The effect of phytohormones on nitrogen content was found non-significant at all stages.

The interaction effect on nitrogen content was also found non-significant at all stages (Table 73).

Table 72. Effect of soil-applied nitrogen and leaf-applied phytohormones and of their interaction on photosynthetic water use efficiency (μ mol mol^{-1}) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose N kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
N_0	41.24	44.27	43.31	45.69	47.79	44.46	51.45	54.13	55.34	52.83	55.07	53.76
N_{60}	41.27	44.51	46.30	42.70	46.91	44.34	52.71	56.09	56.52	52.92	56.96	55.03
N_{90}	42.08	50.89	50.75	50.49	48.92	48.63	55.67	60.12	57.72	59.73	58.70	58.37
N_{120}	41.48	49.29	45.10	48.62	49.02	46.70	54.27	57.32	59.31	58.10	59.00	57.59
Mean	41.52	47.24	46.37	46.88	48.16		53.53	56.92	57.22	55.90	57.37	
	120 DAP						135 DAP					
N_0	61.72	62.26	64.43	64.70	67.81	64.18	73.34	78.54	79.15	77.45	78.06	77.31
N_{60}	65.14	64.83	66.23	66.35	68.42	66.19	76.84	81.55	80.93	80.05	80.44	79.96
N_{90}	70.11	72.91	71.39	72.41	68.89	71.14	81.88	85.28	82.99	84.77	83.17	83.62
N_{120}	68.45	69.41	70.61	71.41	71.88	70.35	79.75	84.04	83.21	82.52	84.35	82.77
Mean	66.36	67.35	68.17	68.72	69.25		77.95	82.35	81.57	81.20	81.51	
	150 DAP											
N_0	72.87	76.30	76.92	75.14	75.70	75.39						
N_{60}	74.41	79.31	79.06	78.10	78.46	77.87						
N_{90}	79.37	84.05	80.99	83.01	81.45	81.77						
N_{120}	77.29	82.00	82.39	80.24	83.00	80.98						
Mean	75.99	80.42	79.84	79.12	79.65							

CD at 5%					
	90	105	120	135	150
Nitrogen	0.15	0.17	0.16	0.17	0.22
Phytohormone	0.17	0.19	0.17	0.19	0.24
Interaction	0.34	0.39	0.35	0.38	0.48

Table 73. Effect of soil-applied nitrogen and leaf-applied phytohormones and of their interaction on nitrogen content (%) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose N kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
N_0	3.15	2.93	3.09	2.85	3.20	3.04	2.88	2.80	2.78	2.75	2.90	2.82
N_{60}	3.42	3.31	3.60	3.38	3.55	3.45	3.22	3.26	3.45	3.30	3.50	3.33
N_{90}	4.08	4.07	3.95	3.99	3.85	3.98	3.95	3.78	3.89	3.80	3.72	3.83
N_{120}	3.65	3.58	3.50	3.72	3.82	3.65	3.58	3.40	3.42	3.60	3.68	3.54
Mean	3.58	3.47	3.54	3.49	3.56		3.41	3.31	3.39	3.36	3.42	
	120 DAP						135 DAP					
N_0	2.60	2.55	2.59	2.62	2.58	2.59	2.00	2.03	2.05	1.96	2.09	2.01
N_{60}	3.06	3.18	3.25	3.15	3.30	3.19	2.06	2.30	2.36	2.22	2.26	2.24
N_{90}	3.56	3.62	3.53	3.60	3.58	3.58	2.72	2.64	2.40	2.51	2.54	2.55
N_{120}	3.32	3.28	3.34	3.18	3.40	3.32	2.48	2.42	2.62	2.43	2.50	2.49
Mean	3.14	3.16	3.18	3.14	3.18		2.32	2.35	2.36	2.33	2.35	
	150 DAP											
N_0	1.67	1.54	1.70	1.59	1.74	1.65						
N_{60}	1.95	1.94	2.12	1.98	1.85	1.97						
N_{90}	2.20	2.11	1.81	1.99	2.18	2.06						
N_{120}	2.05	2.09	1.96	1.89	2.10	2.05						
Mean	1.97	1.92	1.90	1.86	1.97							

CD at 5%					
	90	105	120	135	150
Nitrogen	0.10	0.15	0.10	0.04	0.08
Phytohormone	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS

4.5.2.2.2 Phosphorus content

Phosphorus content remained unaffected by treatments of nitrogen and phytohormones alone as well as in combination at all stages (Table 74).

4.5.2.2.3 Potassium content

The effect of nitrogen, phytohormone and of their interactions on potassium content was found non-significant at all stages (Table 75).

4.5.2.3 Nutrient uptake

The effect of nitrogen and phytohormones alone as well as in combination on nutrient uptake was significant at all stages (Tables 76-78).

4.5.2.3.1 Nitrogen uptake

Of nitrogen treatments, N_{90} gave significantly maximum value at all stages. Minimum value was recorded for the control (N_0) at each growth stage. Treatment N_{90} increased nitrogen uptake by 45.14, 67.20, 66.17, 48.07 and 47.03 per cent over the control at 90, 105, 120, 135 and 150 DAP, respectively.

Regarding phytohormones, maximum value was given by 10^{-5}M Kn at 90, 105 and 120 DAP and by 10^{-5}M GA_3 at 135 and 150 DAP. On the other hand, the water-sprayed control (W_0) gave significant lowest value at all samplings. The increase in nitrogen uptake due to 10^{-5}M Kn was 31.72, 19.11 and 7.78, 10.77 and 8.88 per cent and due to 10^{-5}M GA_3 was 28.28, 18.67, 6.86, 12.69 and 9.66 per cent over the water-sprayed control at 90, 105, 120, 135 and 150 DAP, respectively.

Pertaining to interaction effect, $N_{90}\times10^{-5}$M GA_3 gave significant higher values at all samplings. Significant lowest values was recorded for the control ($N_0\times W_0$). Treatment $N_{90}\times10^{-5}$M GA_3 gave 114.41, 126.85, 95.75, 87.95 and 81.11 per cent increase in nitrogen uptake compared with the control at 90, 105, 120, 135 and 150 DAP, respectively (Table 76).

4.5.2.3.2 Phosphorus uptake

Among nitrogen treatments, N_{90} gave maximum value for phosphorus uptake at all stages. On the other hand, significant lowest value was given by the control (N_0) at all stages. Application of N_{90} gave 10.81, 24.14, 20.70, 17.65 and 17.22 per cent higher value than the control at 90, 105, 120, 135 and 150 DAP, respectively.

Table 74. Effect of soil-applied nitrogen and leaf-applied phytohormones and of their interaction on phosphorus content (%) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose N kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
N_0	0.322	0.309	0.301	0.312	0.323	0.313	0.271	0.258	0.257	0.244	0.266	0.259
N_{60}	0.308	0.324	0.329	0.309	0.306	0.315	0.245	0.261	0.269	0.263	0.252	0.258
N_{90}	0.304	0.314	0.304	0.324	0.318	0.312	0.271	0.246	0.254	0.252	0.261	0.260
N_{120}	0.316	0.300	0.316	0.320	0.306	0.313	0.260	0.250	0.260	0.257	0.260	0.260
Mean	0.313	0.312	0.313	0.316	0.313		0.262	0.258	0.280	0.257	0.260	
	120 DAP						135 DAP					
N_0	0.231	0.215	0.212	0.218	0.231	0.221	0.211	0.194	0.191	0.211	0.209	0.203
N_{60}	0.222	0.229	0.219	0.226	0.226	0.224	0.194	0.201	0.214	0.194	0.212	0.201
N_{90}	0.219	0.236	0.215	0.224	0.215	0.222	0.203	0.196	0.203	0.203	0.206	0.202
N_{120}	0.220	0.210	0.234	0.220	0.220	0.221	0.210	0.200	0.191	0.190	0.198	0.200
Mean	0.223	0.222	0.220	0.222	0.223		0.204	0.198	0.200	0.205	0.204	
	150 DAP											
N_0	0.196	0.174	0.171	0.191	0.189	0.184				CD at 5%		
N_{60}	0.174	0.191	0.194	0.174	0.192	0.183		90	105	120	135	150
N_{90}	0.183	0.178	0.183	0.183	0.186	0.182	Nitrogen	NS	NS	NS	NS	NS
N_{120}	0.181	0.176	0.171	0.170	0.180	0.180	Phytohormone	NS	NS	NS	NS	NS
Mean	0.186	0.183	0.180	0.182	0.184		Interaction	NS	NS	NS	NS	NS

Table 75. Effect of soil-applied nitrogen and leaf-applied phytohormones and of their interaction on potassium content (%) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose N kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
N_0	2.98	2.91	2.78	2.93	2.70	2.86	2.57	2.64	2.68	2.60	2.51	2.60
N_{60}	2.80	2.78	2.92	3.02	2.72	2.84	2.48	2.43	2.51	2.69	2.69	2.56
N_{90}	2.84	2.95	2.81	2.83	2.99	2.88	2.58	2.57	2.61	2.55	2.60	2.56
N_{120}	2.88	2.77	2.82	2.85	2.83	2.83	2.64	2.51	2.49	2.47	2.60	2.55
Mean	2.88	2.85	2.83	2.91	2.81		2.57	2.54	2.57	2.58	2.60	
	120 DAP						135 DAP					
N_0	2.20	2.25	2.20	2.12	2.06	2.17	1.85	1.80	1.90	1.85	1.92	1.86
N_{60}	2.10	2.09	2.20	2.26	2.30	2.19	1.93	1.87	1.93	1.84	1.80	1.88
N_{90}	2.21	2.29	2.07	2.09	2.26	2.19	1.80	1.91	1.94	1.93	1.94	1.91
N_{120}	2.28	2.08	2.20	2.11	2.18	2.17	1.96	1.89	1.80	1.83	1.87	1.87
Mean	2.20	2.18	2.17	2.15	2.20		1.88	1.87	1.89	1.86	1.89	
	150 DAP											
N_0	1.75	1.76	1.63	1.68	1.74	1.71						
N_{60}	1.73	1.63	1.82	1.77	1.75	1.74						
N_{90}	1.78	1.70	1.77	1.66	1.68	1.71						
N_{120}	1.63	1.80	1.75	1.67	1.80	1.74						
Mean	1.72	1.72	1.74	1.71	1.76							

CD at 5%					
	90	105	120	135	150
Nitrogen	NS	NS	NS	NS	NS
Phytohormone	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS

Table 76. Effect of soil-applied nitrogen and leaf-applied phytohormones and of their interaction on nitrogen uptake (mg plant^{-1}) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose N kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
N_0	111	144	155	146	171	144	149	198	203	190	206	189
N_{60}	135	162	196	148	189	165	202	248	253	234	275	239
N_{90}	184	238	188	226	210	209	296	338	316	330	285	316
N_{120}	151	199	183	199	209	185	254	285	270	294	307	277
Mean	145	186	180	180	195		225	267	261	262	268	
	120 DAP						135 DAP					
N_0	306	327	332	339	364	334	390	460	459	431	465	441
N_{60}	424	440	445	453	467	446	438	577	561	533	535	529
N_{90}	532	599	527	586	530	555	666	733	593	671	645	662
N_{120}	484	500	489	488	524	496	587	638	653	609	658	629
Mean	437	467	448	467	471		520	586	567	561	576	
	150 DAP											
N_0	323	348	380	353	375	356						
N_{60}	414	473	502	474	437	454						
N_{90}	535	585	446	531	547	519						
N_{120}	483	530	487	464	552	517						
Mean	439	488	454	455	478							

CD at 5%					
	90	105	120	135	150
Nitrogen	2.00	3.00	4.00	5.00	7.00
Phytohormone	3.00	4.00	5.00	6.00	8.00
Interaction	5.00	8.00	9.00	12.00	17.00

Pertaining to phytohormones, 10^{-5}M Kn gave significant maximum value at 90, 105 and 120 DAP while 10^{-5}M GA_3 gave maximum value at 135 and 150 DAP. The ~~significant~~ lowest effect was noted for the water-sprayed control (W_0) at all stages. The increase in phosphorus uptake due to 10^{-5}M Kn was 36.00, 19.82, 6.48, 9.67 and 11.43 per cent and due to 10^{-5}M GA_3 was 29.60, 19.29, 6.12, 10.11 and 12.17 per cent over the water-sprayed control at 90, 105, 120, 135 and 150 DAP respectively.

Regarding interaction effect, $N_{90}\times10^{-5}$M GA_3 gave significant maximum value at all stages. On the other hand, lowest significant value was recorded for the control ($N_0\times W_0$) at 90, 105 and 135 DAP for $N_0\times10^{-4}$M GA_3 at 120 DAP and for $W_0\times N_{60}$ at 150 DAP. The per cent increase in phosphorus uptake due to $N_{90}\times10^{-5}$M GA_3 was 63.52 at 90 DAP, 57.29 at 105 DAP, 43.75 at 120 DAP, 32.04 at 135 DAP and 30 at 150 DAP over the control (Table 77).

4.5.2.3.3 Potassium uptake

Among nitrogen treatments, N_{90} proved best at all stages. Minimum significant value was given by the control (N_0) at all samplings. The increase in potassium uptake resulted from the application of N_{90} was 11.85, 22.29, 20.94, 20.25 and 19.24 per cent over control at 90, 105, 120, 135 and 150 DAP respectively.

As far as effect of phytohormones was concerned, 10^{-5}M Kn at 90, 105 and 120 DAP and 10^{-5}M GA_3 at 135 and 150 DAP gave maximum value. Significant minimum value was recorded for the water-sprayed control (W_0) at all stages. The increase in potassium uptake due to 10^{-5}M Kn was 31.03, 22.16, 5.96, 9.55 and 10.23 per cent and due to 10^{-5}M GA_3 was 28.45, 21.57, 3.63, 13.13 and 14.17 per cent over the water-sprayed control at 90, 105, 120, 135 and 150 DAP respectively.

Among interactions, $N_{90}\times10^{-5}$M GA_3 gave maximum value at all samplings. At 90 DAP, its value was equalled by that for $N_{90}\times10^{-5}$M Kn and $N_{90}\times10^{-6}$M Kn, and for $N_{90}\times10^{-6}$M Kn at 120 and 135 DAP and for $N_{120}\times10^{-5}$M GA_3 and $N_{120}\times10^{-5}$M Kn at 150 DAP. Minimum value was recorded for the control ($N_0\times W_0$) at all stages except 90 DAP, at which its value was equal to $N_{60}\times W_0$. The increase in potassium uptake due to $N_{90}\times10^{-5}$M GA_3 over the control at 90, 105, 120, 135 and 150 DAP was 62.86, 72.18, 32.43, 46.81 and 38.53 per cent respectively (Table 78).

Table 77. Effect of soil-applied nitrogen and leaf-applied phytohormones and of their interaction on phosphorus uptake (mg plant^{-1}) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose N kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
N_0	11.13	14.60	15.10	16.00	17.20	14.80	14.00	18.20	18.80	17.00	18.90	17.40
N_{60}	12.10	15.20	17.90	14.90	16.20	15.30	15.30	19.90	19.70	18.60	19.30	18.60
N_{90}	13.70	18.20	14.50	18.30	17.40	16.40	20.30	22.02	20.60	21.90	21.60	21.60
N_{120}	13.10	16.70	16.50	17.10	17.00	16.10	18.40	21.00	20.70	21.00	21.68	20.70
Mean	12.50	16.20	16.00	15.60	17.00		17.00	20.28	20.00	19.62	20.37	
	120 DAP						135 DAP					
N_0	27.20	27.50	27.10	28.30	32.60	28.54	41.20	44.00	42.80	46.90	45.90	44.20
N_{60}	30.80	31.70	30.00	31.71	32.45	31.33	41.30	49.20	50.80	46.60	50.20	47.60
N_{90}	32.70	39.10	32.00	36.40	31.80	34.40	49.70	54.40	50.20	54.30	51.40	52.00
N_{120}	32.10	32.00	34.30	33.77	33.90	33.21	49.70	52.80	47.60	47.63	52.11	50.50
Mean	30.70	32.58	30.85	32.55	32.69		45.50	50.10	47.90	48.85	49.90	
	150 DAP											
N_0	38.00	39.30	38.20	42.30	41.40	39.84						
N_{60}	36.90	46.60	46.00	42.00	45.30	43.40						
N_{90}	44.50	49.36	45.10	48.90	46.30	46.70						
N_{120}	45.00	44.62	42.50	41.75	47.29	45.30						
Mean	41.10	46.10	42.95	43.75	45.08							

CD at 5%					
	90	105	120	135	150
Nitrogen	0.08	0.04	0.09	0.03	0.05
Phytohormone	0.09	0.05	0.10	0.04	0.06
Interaction	0.17	0.09	0.20	0.07	0.13

Table 78. Effect of soil-applied nitrogen and leaf-applied phytohormones and of their interaction on potassium uptake (mg plant^{-1}) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose N kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
N_0	105	138	139	150	144	135	133	187	197	179	178	175
N_{60}	110	131	159	146	144	138	155	185	184	170	206	184
N_{90}	128	171	134	160	163	151	193	229	212	221	215	214
N_{120}	119	154	147	152	158	146	187	211	199	202	217	203
Mean	116	149	145	152	152		167	203	198	198	204	
	120 DAP						135 DAP					
N_0	259	288	272	276	291	277	361	408	426	411	421	405
N_{60}	291	289	309	325	325	308	411	458	459	436	428	440
N_{90}	330	343	319	340	335	335	441	530	480	516	496	487
N_{120}	332	335	309	328	330	327	463	499	449	459	492	476
Mean	303	314	302	317	320		419	474	453	456	459	
	150 DAP											
N_0	340	398	364	368	384	369						
N_{60}	367	398	431	424	413	407						
N_{90}	433	471	436	443	418	440						
N_{120}	382	471	435	437	465	438						
Mean	381	435	417	418	420							

CD at 5%					
	90	105	120	135	150
Nitrogen	5.00	3.00	2.00	6.00	5.00
Phytohormone	6.00	3.00	3.00	7.00	6.00
Interaction	11.00	7.00	6.00	13.00	12.00

4.5.3 Yield characteristics

Effect of nitrogen treatments and phytohormones alone and of their interaction on yield parameters was significant (Tables 79-85).

4.5.3.1 Leaf number per plant

Maximum and minimum values were given by N_{90} and the control (N_0) respectively at all samplings. The increase in leaf number due to N_{90} over the control was 22.87, 25.74, 25.11, 20.73 and 21.57 per cent at 90, 105, 120, 135 and 150 DAP respectively.

As far as phytohormone effect was concerned, 10^{-5}M GA_3 gave significant maximum value at all stages. On the other hand minimum value was noted for the water-sprayed control (W_0) at each sampling. Treatment 10^{-5}M GA_3 gave 50.01, 57.79, 37.73, 31.46 and 33.48 per cent higher value for leaf number than the water-sprayed control at 90, 105, 120, 135 and 150 DAP respectively.

With regard to interaction effect, $N_{90}\times10^{-5}$M GA_3 gave significant maximum value for leaf number at all stages. Significant minimum value was recorded for the control ($N_0\times W_0$) at all samplings. The per cent increase in leaf number due to $N_{90}\times10^{-5}$M GA_3 compared with the control was 126.98 at 90 DAP, 138.88 at 105 DAP, 78.54 at 120 DAP, 61.55 at 135 DAP and 68.84 at 150 DAP (Table 79).

4.5.3.2 Branch number per plant

Among treatments of nitrogen, N_{90} gave significant maximum value at each sampling. On the other hand the control (N_0) gave significantly minimum value at each stage. The per cent increase in branch number resulted from application of N_{90} over the control was 42.02, 25.69, 26.71, 14.82 and 17.94 per cent at 90, 105, 120, 135 and 150 DAP respectively.

Pertaining to the effect of phytohormones, 10^{-5}M GA_3 gave significant maximum value at all stages except 90 DAP, at which it was equal to 10^{-5}M Kn, 10^{-6}M Kn and 10^{-4}M GA_3 in effect. ~~Significant~~ The lowest value was given by the water-sprayed control (W_0). In comparison with the water-sprayed control 10^{-5}M GA_3 gave 48.45, 37.88, 57.18, 28.28 and 29.55 per cent higher value for branch number at 90, 105, 120, 135 and 150 DAP respectively.

Table 79. Effect of soil-applied nitrogen and leaf-applied phytohormones and of their interaction on leaf number per plant of *Mentha arvensis* L. at five growth stages.

Fertilizer dose N kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
N_0	38.33	65.00	69.00	61.67	63.33	59.47	78.00	148.00	143.33	135.00	143.33	129.53
N_{60}	48.00	68.33	64.67	64.33	69.67	63.00	103.33	151.67	152.00	153.33	156.33	143.33
N_{90}	59.00	87.00	68.33	81.33	79.67	75.07	117.00	186.33	168.00	175.00	168.00	162.87
N_{120}	54.00	78.67	69.33	68.67	73.00	68.73	116.33	168.33	161.33	165.67	167.00	155.73
Mean	49.83	74.75	67.83	69.00	71.42		103.67	163.58	156.17	157.25	158.67	
	120 DAP						135 DAP					
N_0	205.00	271.67	280.00	232.00	236.33	245.00	362.33	444.67	503.00	430.00	443.67	436.73
N_{60}	215.00	264.67	285.33	241.33	264.00	254.07	393.00	495.00	513.33	442.00	485.00	465.67
N_{90}	236.67	366.00	307.67	334.33	328.00	314.53	422.67	585.33	521.00	572.33	535.00	527.27
N_{120}	232.00	321.67	301.00	301.00	320.67	295.27	410.33	563.00	527.33	545.00	540.00	517.13
Mean	222.17	303.00	293.50	277.08	287.25		397.08	522.00	516.17	497.33	500.92	
	150 DAP											
N_0	343.33	439.67	494.67	423.33	437.33	427.67						
N_{60}	383.00	482.33	506.00	434.00	473.33	455.73						
N_{90}	413.00	579.67	514.00	563.33	529.67	519.93						
N_{120}	399.00	551.67	518.33	540.00	531.33	508.07						
Mean	384.58	513.33	508.25	490.17	492.92							

CD at 5%					
	90	105	120	135	150
Nitrogen	1.06	1.92	1.73	1.76	1.84
Phytohormone	1.18	2.15	1.93	1.97	2.06
Interaction	2.37	4.30	3.87	3.94	4.12

Regarding interaction effect, $N_{90}\times10^{-5}$M GA_3 gave maximum value at all stages. The control ($N_0\times W_0$) gave significant minimum value at each sampling stage. The per cent increase in branch number due to $N_{90}\times10^{-5}$M GA_3 over the control was 126.38, 79.48, 109.18, 70.27 and 75.49 at 90, 105, 120, 135 and 150 DAP respectively (Table 80).

4.5.3.3 Leaf yield per plant

Significant maximum value was noted for N_{90} and minimum for the control (N_0) at all samplings. The per cent increase in leaf yield due to N_{90} over the control was 12.66, 25.38, 22.06, 19.65 and 19.32 at 90, 105, 120, 135 and 150 DAP respectively.

Among phytohormones, 10^{-5}M Kn gave maximum value at 90, 105 and 120 DAP, and 10^{-5}M GA_3 at 135 and 150 DAP. However, at 90, 105 and 120 DAP, the value for 10^{-5}M Kn was equal to that for 10^{-5}M GA_3. Significant minimum value was recorded for the water-sprayed control (W_0) at all stages. The increase in leaf yield due to 10^{-5}M Kn was 45.56, 11.98, 6.27, 6.82 and 7.07 per cent and due to 10^{-5}M GA_3 was 44.90, 10.99, 6.06, 9.21 and 8.81 per cent over the control at 90, 105, 120, 135 and 150 DAP respectively.

Pertaining to the interaction effect, $N_{90}\times10^{-5}$M GA_3 gave maximum value at all stages. Significant minimum value was recorded for the control ($N_0\times W_0$) at all stages. The interaction $N_{90}\times10^{-5}$M GA_3 gave 84.0, 58.31, 44.22, 37.66 and 38.84 per cent higher value for leaf yield compared with the control at 90, 105, 120, 135 and 150 DAP respectively (Table 81).

4.5.3.4 Stem yield per plant

Of nitrogen treatments, N_{90} gave significant maximum value at all stages of sampling. The control (N_0) gave significant minimum value at all samplings. The increase in stem yield due to N_{90} over the control was 20.93, 19.77, 18.63, 18.51 and 18.01 per cent at 90, 105, 120, 135 and 150 DAP respectively.

Pertaining to phytohormones, 10^{-5}M Kn at 105 and 120 DAP and 10^{-5}M GA_3 at 135 and 150 DAP had significant maximum values, while at 90 DAP both these treatments were equal in their effect. Significant minimum value was given by the water-sprayed control (W_0) at all stages. The per cent increase in stem yield due to

Table 80. Effect of soil-applied nitrogen and leaf-applied phytohormones and of their interaction on branch number per plant of *Mentha arvensis* L. at five growth stages.

Fertilizer dose N kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
N_0	6.33	7.67	12.00	7.67	8.33	8.40	14.67	20.67	18.67	18.00	18.67	18.14
N_{60}	6.33	8.33	9.67	10.33	10.67	9.07	16.00	21.33	19.33	19.33	20.00	19.20
N_{90}	9.33	14.33	11.00	12.67	12.33	11.93	18.00	26.33	25.33	22.67	21.67	22.80
N_{120}	7.67	13.67	10.30	12.33	12.00	11.19	17.33	22.67	20.00	20.67	21.33	20.40
Mean	7.41	11.00	10.74	10.75	10.83		16.50	22.75	21.08	20.17	20.42	
	120 DAP						135 DAP					
N_0	21.67	34.00	36.00	31.67	32.67	31.20	37.00	53.00	54.67	49.00	51.00	49.93
N_{60}	24.33	35.67	33.67	33.67	36.33	32.73	44.30	54.67	54.00	52.33	53.00	51.67
N_{90}	27.33	45.33	41.00	44.00	40.00	39.53	50.67	63.00	55.33	59.67	58.00	57.33
N_{120}	26.33	41.67	38.67	40.67	41.33	37.73	48.33	60.67	55.00	57.33	57.33	55.73
Mean	24.92	39.17	37.33	37.50	37.58		45.08	57.83	54.75	54.58	54.83	
	150 DAP											
N_0	35.33	52.67	54.00	48.00	50.00	47.20						
N_{60}	43.67	54.00	53.33	51.33	52.33	50.93						
N_{90}	50.33	62.00	54.67	58.67	56.67	55.67						
N_{120}	47.33	59.33	54.33	57.00	56.33	54.87						
Mean	43.42	56.25	54.08	53.75	53.83							

CD at 5%					
	90	105	120	135	150
Nitrogen	0.59	0.65	0.62	0.73	0.55
Phytohormone	0.66	0.73	0.69	0.82	0.62
Interaction	1.25	1.46	1.39	1.63	1.42

Table 81. Effect of soil-applied nitrogen and leaf-applied phytohormones and of their interaction on leaf yield (g plant^{-1}) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose N kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
N_0	7.50	12.17	11.47	12.87	13.23	11.45	13.60	16.40	17.87	15.87	18.23	16.39
N_{60}	9.17	13.12	12.23	11.87	12.60	11.80	17.00	18.20	18.70	17.47	18.30	17.93
N_{90}	10.30	13.80	13.60	13.20	13.60	12.90	20.07	21.53	19.73	20.80	20.60	20.55
N_{120}	9.10	13.20	11.12	12.65	13.10	11.83	18.43	20.60	20.27	19.43	20.27	19.80
Mean	9.02	13.07	12.10	12.65	13.13		17.28	19.18	19.14	18.39	19.35	
	120 DAP						135 DAP					
N_0	27.09	31.13	30.37	31.00	32.00	30.32	45.40	48.37	49.23	49.57	49.70	48.45
N_{60}	33.47	33.10	33.37	34.15	34.00	33.62	50.20	54.73	52.97	52.70	53.60	52.84
N_{90}	36.10	39.07	35.63	37.63	36.63	37.01	55.27	62.50	54.93	60.30	56.83	57.97
N_{120}	34.73	36.03	34.73	36.07	36.97	35.71	55.07	59.30	56.50	55.30	59.83	57.20
Mean	32.84	34.83	33.53	34.71	34.90		51.48	56.22	53.41	54.47	54.99	
	150 DAP											
N_0	44.87	48.23	49.10	49.40	49.53	48.23						
N_{60}	50.00	54.23	52.82	52.57	53.45	52.61						
N_{90}	55.10	62.30	53.48	60.17	56.68	57.55						
N_{120}	54.90	58.30	56.17	55.17	59.70	56.85						
Mean	51.22	55.77	52.89	54.33	54.84							

	CD at 5%				
	90	105	120	135	150
Nitrogen	0.14	0.18	0.20	0.21	0.14
Phytohormone	0.16	0.21	0.22	0.29	0.16
Interaction	0.32	0.41	0.44	0.52	0.31

10^{-5}M GA_3 was 29.66, 34.47, 4.37, 17.46 and 16.76 and due to 10^{-5}M Kn was 29.09, 40.55, 7.53, 17.46 and 17.61 per cent over the water-sprayed control at 90, 105, 120, 135 and 150 DAP respectively.

Regarding interaction effect, $N_{90}\times10^{-5}$M GA_3 gave maximum value at all sampling stages. Significant minimum value was given by the control (N_0W_0) at all stages. The per cent increase in stem yield due to $N_{90}\times10^{-5}$M GA_3 over the control was 76.06, 93.69, 38.39, 47.22 and 47.94 at 90, 105, 120, 135 and 150 DAP respectively (Table 82).

4.5.3.5 Herb yield per plant

Of nitrogen treatments, significant maximum value was recorded for N_{90} at all samplings. On the other hand, significant lowest value was noted for the control (N_0). The increase in the herb yield due to N_{90} over the control was 15.27, 23.73, 20.52, 18.61 and 18.68 per cent at 90, 105, 120, 135 and 150 DAP respectively.

With regard to leaf-applied treatments, 10^{-5}M Kn gave maximum value at 90, 105 and 120 DAP, however its effect was at par with that of 10^{-5}M GA_3 at 90 DAP and with that of 10^{-6}M Kn at 120 DAP. Treatment 10^{-5}M GA_3 gave maximum value at 135 and 150 DAP. The effect of the water-sprayed control (W_0) was significantly lowest at all stages. The increase in herb yield due to 10^{-5}M Kn was 37.18, 21.11, 6.60, 10.15 and 10.12 per cent and due to 10^{-5}M GA_3 was 34.80, 21.07, 5.16, 13.00 and 12.19 per cent over the water sprayed control at 90, 105, 120, 135 and 150 DAP respectively.

Regarding interaction effect, $N_{90}\times10^{-5}$M GA_3 gave maximum value at each sampling. The effect of the control ($N_0\times W_0$) was significantly lowest at all stages. In comparison with the control, $N_{90}\times10^{-5}$M GA_3 gave 78.91, 73.01, 40.81, 42.13 and 43.33 per cent higher herb yield at 90, 105, 120, 135 and 150 DAP respectively (Table 83).

4.5.3.6 Oil content

Among nitrogen treatments, N_{90} proved best at all stages. Lowest value was recorded for the control (N_0) at each growth stage. Treatment N_{90} gave 10.42, 11.11, 9.38, 9.09 and 11.43 per cent higher value than the control at 90, 105, 120, 135 and 150 DAP respectively.

Table 82. Effect of soil-applied nitrogen and leaf-applied phytohormones and of their interaction on stem yield (g plant^{-1}) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose N kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
N_0	7.10	10.37	9.87	10.17	10.73	9.65	9.67	14.97	14.83	15.13	15.70	14.21
N_{60}	8.57	11.33	8.93	9.83	11.33	10.00	11.20	15.57	15.60	13.60	17.00	14.45
N_{90}	9.97	12.50	12.20	12.27	11.40	11.67	13.67	18.73	16.87	18.27	17.57	17.02
N_{120}	9.55	11.43	11.67	11.37	11.97	11.20	13.50	15.33	17.50	17.33	17.23	16.18
Mean	8.80	11.41	10.67	10.91	11.36		12.01	16.15	16.20	16.08	16.88	
	120 DAP						135 DAP					
N_0	25.63	26.47	27.27	27.50	31.57	27.69	42.50	53.70	51.63	49.20	50.35	49.48
N_{60}	28.57	28.20	29.20	29.00	30.53	29.10	45.57	55.73	53.97	53.80	54.50	52.71
N_{90}	31.17	35.47	32.50	34.58	30.53	32.85	54.57	62.57	58.63	60.00	57.43	58.64
N_{120}	30.87	31.17	32.60	32.90	32.37	31.98	51.37	55.90	58.23	57.50	58.63	56.33
Mean	29.06	30.33	30.39	31.00	31.25		48.50	56.97	55.62	55.12	55.23	
	150 DAP											
N_0	42.20	53.53	51.50	49.05	49.90	49.24						
N_{60}	45.43	55.62	53.83	53.67	54.38	52.59						
N_{90}	54.43	42.43	57.50	59.90	56.30	58.11						
N_{120}	51.23	55.77	58.10	55.37	58.50	56.19						
Mean	48.33	56.84	55.23	54.50	54.77							

	CD at 5%				
	90	105	120	135	150
Nitrogen	0.30	0.21	0.31	0.19	0.24
Phytohormone	0.33	0.23	0.35	0.21	0.26
Interaction	0.66	0.47	0.70	0.42	0.53

Table 83. Effect of soil-applied nitrogen and leaf-applied phytohormones and of their interaction on herb yield (g plant^{-1}) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose N kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
N_0	14.70	22.54	21.34	23.04	23.96	21.12	23.27	31.83	32.83	31.00	33.93	30.17
N_{60}	17.73	24.45	21.16	21.70	23.93	21.79	28.20	33.77	34.30	31.07	35.30	32.53
N_{90}	19.73	26.30	25.80	25.47	25.00	24.46	33.74	40.26	36.60	39.07	38.17	37.37
N_{120}	18.65	24.63	22.79	24.02	25.07	23.03	31.93	35.93	37.77	36.77	37.50	35.98
Mean	17.70	24.48	22.72	23.56	24.49		29.28	35.45	35.38	34.48	36.23	
	120 DAP						135 DAP					
N_0	52.93	57.60	57.63	58.50	63.57	58.05	87.90	102.07	100.86	98.77	100.85	98.34
N_{60}	62.04	61.30	62.57	63.15	64.63	62.74	95.77	110.46	106.94	106.50	108.10	105.83
N_{90}	67.27	74.53	68.13	73.22	67.16	70.06	110.17	124.93	113.56	120.30	114.26	116.64
N_{120}	65.60	67.20	67.33	68.97	69.34	67.69	106.43	115.20	114.73	112.80	118.46	113.52
Mean	61.96	65.16	63.92	65.96	66.05		100.07	113.17	109.02	109.59	110.23	
	150 DAP											
N_0	87.07	101.76	100.60	98.45	99.43	97.46						
N_{60}	95.43	109.85	106.65	106.24	107.83	105.20						
N_{90}	109.53	124.80	110.98	120.07	112.98	115.67						
N_{120}	106.13	114.07	114.27	110.54	118.20	112.64						
Mean	99.54	112.62	108.13	108.83	109.61							

	CD at 5%				
	90	105	120	135	150
Nitrogen	0.36	0.26	0.33	0.31	0.28
Phytohormone	0.41	0.29	0.37	0.34	0.31
Interaction	0.81	0.58	0.74	0.68	0.63

As far as phytohormone effect was concerned, 10^{-5}M GA_3 gave maximum values at 90, 105, 120 and 150 DAP however its effect was at par with that of 10^{-4}M GA_3 at 90 DAP, with that of all other hormone containing treatments at 105 DAP, with that of 10^{-5}M Kn at 120 DAP and with that of 10^{-6}M and 10^{-5}M Kn at 150 DAP. At 135 DAP, 10^{-5}M Kn and 10^{-6}M Kn being at par in their effect gave maximum value. Minimum value was registered for the water-sprayed control (W_0) at all stages. Treatment 10^{-5}M GA_3 increased oil content by 6.00, 7.41, 13.11, 21.30 and 23.16 per cent and 10^{-5}M Kn by 2.00, 7.41, 13.11, 24.07 and 23.16 per cent respectively over the water-sprayed control at 90, 105, 120, 135 and 150 DAP respectively.

Regarding interaction effect, $N_{90}\times10^{-5}$M GA_3 gave maximum value for oil content at all samplings, however its effect was at par with that of $N_{90}\times10^{-4}$M GA_3, $N_{120}\times10^{-5}$M GA_3 and $N_{60}\times10^{-5}$M GA_3 at 90 DAP, with that of $N_{90}\times10^{-6}$M Kn, $N_{120}\times10^{-5}$M GA_3 and $N_{90}\times10^{-5}$M Kn at 105 DAP, with that of $N_{90}\times10^{-6}$M Kn at 120 DAP, with that of $N_{120}\times10^{-5}$M Kn and $N_{90}\times10^{-6}$M Kn at 135 DAP, and with that of $N_{90}\times10^{-4}$M GA_3 and $N_{120}\times10^{-5}$M Kn at 150 DAP. On the other hand, the control ($N_0\times W_0$) gave minimum value at all stages of growth except at 90 DAP where the lowest value was recorded for $N_0\times10^{-6}$M Kn. The per cent increase in oil content resulted from the application of $N_{90}\times10^{-5}$M GA_3 over the control was 17.02, 23.53, 32.14, 45.74 and 45.88 per cent at 90, 105, 120, 135 and 150 DAP respectively (Table 84).

4.5.3.7 Oil yield per plant

Significant maximum value for oil yield was given by N_{90} and minimum by the control (N_0) at all stages of sampling. The per cent increase in oil yield resulted from the application of N_{90} was 23.06, 40.18, 32.05, 28.65 and 31.82 over the control at 90, 105, 120, 135 and 150 DAP respectively.

As far as phytohormone effect was concerned, 10^{-5}M GA_3 gave maximum value at all stages. On the other hand, ~~significant~~ the lowest value was given by the water-sprayed control (W_0). Treatment 10^{-5}M GA_3 gave 54.30, 21.65, 19.95, 33.34 and 34.12 per cent 10^{-5}M Kn, 45.70, 20.04, 18.71, 29.49 and 30.52 per cent higher oil yield than the water-sprayed control at 90, 105, 120, 135 and 150 DAP respectively.

Table 84. Effect of soil-applied nitrogen and leaf-applied phytohormones and of their interaction on oil content (%) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose N kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
N_0	0.47	0.50	0.51	0.46	0.48	0.48	0.51	0.55	0.56	0.53	0.55	0.54
N_{60}	0.50	0.53	0.51	0.48	0.50	0.50	0.54	0.57	0.57	0.54	0.57	0.55
N_{90}	0.52	0.55	0.55	0.52	0.52	0.53	0.57	0.63	0.58	0.62	0.59	0.60
N_{120}	0.51	0.54	0.51	0.51	0.51	0.52	0.54	0.60	0.59	0.60	0.61	0.59
Mean	0.50	0.53	0.52	0.49	0.51		0.54	0.58	0.58	0.57	0.58	
	120 DAP						135 DAP					
N_0	0.56	0.68	0.65	0.63	0.68	0.64	0.94	1.25	1.26	1.30	1.33	1.21
N_{60}	0.60	0.68	0.63	0.65	0.67	0.65	1.01	1.31	1.28	1.34	1.33	1.25
N_{90}	0.65	0.74	0.70	0.72	0.70	0.70	1.19	1.37	1.34	1.35	1.34	1.32
N_{120}	0.63	0.69	0.69	0.67	0.69	0.67	1.16	1.29	1.31	1.32	1.36	1.29
Mean	0.61	0.70	0.67	0.67	0.69		1.08	1.31	1.30	1.33	1.34	
	150 DAP											
N_0	0.89	1.10	1.10	1.12	1.09	1.06						
N_{60}	0.92	1.14	1.12	1.16	1.17	1.10						
N_{90}	1.01	1.24	1.23	1.17	1.18	1.17						
N_{120}	0.98	1.20	1.14	1.17	1.23	1.14						
Mean	0.95	1.17	1.15	1.16	1.17							

CD at 5%					
	90	105	120	135	150
Nitrogen	0.01	0.01	0.01	0.01	0.01
Phytohormone	0.01	0.01	0.02	0.01	0.01
Interaction	0.02	0.02	0.03	0.02	0.02

Pertaining to interaction effect, $N_{90}\times10^{-5}$M GA_3 gave significant maximum values at all stages except at 90 DAP at which its value was equalled by that for $N_{90}\times10^{-4}$M GA_3. The control ($N_0\times W_0$) gave significantly ~~minimum~~ lowest values at all stages. Treatment of $N_{90}\times10^{-5}$M GA_3 increased oil yield over control by 115.01, 95.39, 85.43, 99.16 and 93.46 per cent at 90, 105, 120, 135 and 150 DAP, respectively (Table 85).

4.6 Experiment 6

This experiment was carried out to examine the effect of soil-applied phosphorus (0, 20, 30 and 40 kg/ha) and leaf-applied phytohormnes (W_0, 10^{-5}M GA_3, 10^{-4}M GA_3, 10^{-6}M Kn and 10^{-5}M Kn) alone and of their interaction on performance of *Mentha arvensis* L. The details of results are given below and summarized in tables (Tables 86-114).

4.6.1. Growth characteristics

Effect of soil-applied phosphorus and leaf-applied phytohormones alone as well as in combination (interaction) on growth characteristics at all stages studied was significant, except effect of phosphorus alone at 135 and 150 DAP on specific leaf weight and individual effect of both phosphorus and phytohormones at 150 DAP on leaf area ratio and their interaction effect at all stages on leaf area ratio, specific leaf area and specific leaf weight (Tables 86-96).

4.6.1.1 Plant height

Increasing doses of phosphorus uptake P_{30} enhanced plant height linearly at all stages. The control (P_0) gave ~~significa~~nt lowest value at all samplings. The per cent increase in plant height due to P_{30} over the control was 12.30, 16.27, 13.14, 12.30 and 12.85 at 90, 105, 120, 135 and 150 DAP, respectively.

Among phytohormones, 10^{-4}M GA_3 gave significant maximum value at all samplings. The increase in plant height due to 10^{-4}M GA_3 in comparison with the water-sprayed control (W_0), giving minimum value was 22.03, 27.54, 31.87,48.98 and 49.22 per cent at 90, 105, 120, 135 and 150 DAP, respectively. Moreover, 10^{-5}M GA_3 enhanced the plant height by 15.39, 22.19, 22.74, 31.01 and 31.09 and 10^{-5}M Kn by 15.33, 16.38, 21.97, 26.62 and 26.68 per cent over the control at 90, 105, 120, 135 and 150 DAP, respectively.

Table 85. Effect of soil-applied nitrogen and leaf-applied phytohormones and of their interaction on oil yield (g plant^{-1}) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose N kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
N_0	3.53	6.08	5.85	5.92	6.35	5.55	6.94	9.02	10.01	8.41	10.03	8.88
N_{60}	4.59	6.95	6.24	5.70	6.30	5.95	9.18	10.47	10.66	9.43	10.25	10.00
N_{90}	5.36	7.59	7.48	6.86	7.21	6.87	11.24	13.56	11.44	12.90	12.15	12.26
N_{120}	4.64	7.13	5.67	6.45	6.68	6.11	9.95	12.36	11.96	11.66	12.36	11.66
Mean	4.53	6.94	6.31	6.23	6.60		9.33	11.35	11.02	10.60	11.20	
	120 DAP						135 DAP					
N_0	15.17	21.17	19.74	19.53	21.76	19.47	42.68	62.88	62.03	63.45	64.11	59.03
N_{60}	20.08	22.51	21.02	22.20	22.78	21.72	50.70	73.34	67.80	68.51	69.68	66.01
N_{90}	23.47	28.13	24.94	26.72	25.64	25.78	65.77	85.00	71.96	80.80	76.15	75.94
N_{120}	21.88	24.88	23.96	24.17	25.51	24.08	63.88	76.50	74.02	70.23	78.98	72.72
Mean	20.15	24.17	22.41	23.16	23.92		55.78	74.43	68.95	70.75	72.23	
	150 DAP											
N_0	39.93	53.05	52.54	55.33	53.99	50.97						
N_{60}	46.00	61.82	59.16	60.98	62.54	58.10						
N_{90}	55.65	77.25	65.78	70.40	66.88	67.19						
N_{120}	53.80	69.96	64.55	69.18	71.64	65.83						
Mean	48.85	65.52	60.51	63.97	63.76							

	CD at 5%				
	90	105	120	135	150
Nitrogen	0.08	0.16	0.21	0.31	0.27
Phytohormone	0.09	0.18	0.23	0.35	0.31
Interaction	0.19	0.37	0.46	0.70	0.62

Regarding interaction effect, $P_{40}\times10^{-4}$M GA_3 gave significant maximum value at all stages, except at 90 DAP at which its value was equalled by that for $P_{30}\times10^{-5}$M Kn. The water-sprayed control ($P_0\times W_0$) gave significant minimum value at all stages. The increase in plant height due to $P_{40}\times10^{-4}$M GA_3 over the control was 45.31, 49.20, 70.30, 77.29 and 79.59 per cent at 90, 105, 120, 135 and 150 DAP respectively (Table 86).

4.6.1.2 Root length

Of phosphorus treatments, maximum value was recorded for P_{30} and minimum for P_0 at all stages. Treatment P_{30} gave 23.29, 31.12, 13.96, 16.25 and 17.39 per cent higher value for root length in comparison with the control at 90, 105, 120, 135 and 150 DAP respectively.

Regarding phytohormones, 10^{-5}M Kn at all stages gave maximum value for root length, however its effect was equal to that of 10^{-5}M GA_3 at 90 DAP. Significant minimum value was given by the water-sprayed control (W_0). The increase in root length due to 10^{-5}M Kn over the water-sprayed control was 23.79, 23.94, 24.56, 29.90 and 27.73 per cent at 90, 105, 120, 135 and 150 DAP respectively.

Among interactions, $P_{30}\times10^{-6}$M Kn gave maximum value at all stages, however its effect was at par with that of $P_{30}\times10^{-5}$M GA_3 and $P_{40}\times10^{-5}$M GA_3 at 90 DAP and with that of $P_{30}\times10^{-5}$M Kn at 105, 120 and 135 DAP. The value given by the control ($P_0\times W_0$) was significantly lowest at all samplings. The per cent increase in root length due to $P_{30}\times10^{-6}$M Kn over the control was 63.74, 59.79, 49.29, 47.32 and 25.72 at 90, 105, 120, 135 and 150 DAP respectively (Table 87).

4.6.1.3 Leaf area per plant

Application of P_{30} proved best for leaf area per plant at all stages. Treatment P_{30} increased leaf area by 23.41, 27.86, 15.97, 7.91 and 18.56 per cent in comparison with the respective control (P_0) at 90, 105, 120, 135 and 150 DAP respectively.

With regard to phytohormones, significant maximum value was registered for 10^{-5}M Kn at 105 and 120 DAP and for 10^{-5}M GA_3 at 135 and 150 DAP. However at 90 DAP, the maximum value noted for 10^{-5}M Kn was equalled by that for 10^{-5}M GA_3. The water-sprayed control (W_0) gave significantly minimum value at all stages. The per cent increase in leaf area due to 10^{-5}M Kn was 51.96, 71.11, 36.87, 28.84 and

Table 86. Effect of soil-applied phosphorus and leaf-applied phytohormones and of their interaction on plant height (cm) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose P kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
P_0	32.00	39.17	43.17	37.83	38.83	38.20	41.67	49.17	51.56	44.67	45.83	47.50
P_{20}	36.50	41.00	42.50	38.33	40.17	39.70	45.83	53.83	55.50	47.33	48.83	50.26
P_{30}	39.00	43.50	44.17	41.83	46.00	42.90	47.33	55.50	56.83	56.17	60.33	55.23
P_{40}	37.00	44.17	46.50	37.50	41.67	41.37	46.17	55.67	62.17	54.83	55.63	54.89
Mean	36.13	41.96	44.09	38.87	41.67		45.25	55.29	57.71	50.75	52.66	
	120 DAP						135 DAP					
P_0	47.17	67.33	71.30	68.83	60.00	60.93	56.50	86.50	91.67	72.83	74.33	76.37
P_{20}	54.17	65.66	62.17	60.83	64.33	61.43	64.33	80.83	95.17	75.17	76.67	78.43
P_{30}	59.83	67.33	74.33	66.33	76.83	68.93	70.50	83.83	97.33	78.83	98.33	85.76
P_{40}	57.33	67.83	80.33	64.50	65.33	67.06	66.67	86.83	100.17	79.00	77.33	82.00
Mean	54.62	67.04	72.03	62.62	66.62		64.50	84.50	96.09	76.46	81.67	
	150 DAP											
P_0	55.50	85.33	90.67	72.17	73.67	75.47						
P_{20}	64.00	80.33	94.50	74.67	76.17	77.93						
P_{30}	70.00	83.33	96.67	78.17	97.67	85.17						
P_{40}	66.17	86.17	99.67	78.17	76.33	81.30						
Mean	63.92	83.79	95.38	75.79	80.96							

CD at 5%					
	90	105	120	135	150
Phosphorus	0.30	0.28	0.33	0.30	0.32
Phytohormone	0.34	0.31	0.37	0.34	0.37
Interaction	0.68	0.63	0.73	0.68	0.71

Table 87. Effect of soil-applied phosphorus and leaf-applied phytohormones and of their interaction on root length (cm) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose P kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
P_0	11.50	14.67	13.83	15.00	15.83	14.17	14.50	16.33	15.50	16.83	17.50	16.13
P_{20}	13.33	17.50	14.50	15.83	17.00	15.63	15.00	18.17	16.50	18.17	19.33	17.43
P_{30}	15.50	18.50	16.83	18.83	17.67	17.47	19.00	22.33	18.67	23.17	22.57	21.15
P_{40}	15.00	18.17	15.67	17.67	18.00	16.90	16.50	20.83	19.83	20.83	21.17	19.83
Mean	13.83	17.21	15.21	16.83	17.12		16.25	19.42	17.62	19.75	20.14	
	120 DAP						135 DAP					
P_0	19.00	23.83	21.67	24.00	25.00	22.57	21.25	28.50	26.50	30.50	32.00	28.50
P_{20}	20.67	24.50	22.17	25.50	26.17	23.80	26.50	29.00	28.17	34.33	34.17	30.43
P_{30}	24.00	25.33	23.50	28.33	28.17	25.87	29.50	32.67	30.33	36.83	36.33	33.13
P_{40}	22.50	25.50	23.00	26.33	27.17	24.90	29.00	30.67	28.67	35.50	35.83	31.93
Mean	21.54	24.79	22.59	26.04	26.63		27.58	30.21	28.41	34.29	34.58	
	150 DAP											
P_0	24.00	27.83	25.50	27.50	31.17	27.20						
P_{20}	25.50	26.50	27.33	33.17	33.17	29.13						
P_{30}	29.17	31.67	28.83	35.83	34.17	31.93						
P_{40}	28.17	29.67	27.17	34.17	32.83	30.40						
Mean	26.71	28.92	27.21	32.67	32.84							

CD at 5%					
	90	105	120	135	150
Phosphorus	0.35	0.34	0.33	0.29	0.43
Phytohormone	0.40	0.38	0.37	0.32	0.48
Interaction	0.79	0.76	0.73	0.64	0.79

31.65 per cent and due to 10^{-5}M GA_3, 51.07, 64.19, 35.59, 29.90 and 33.01 per cent compared with the water-sprayed control at 90, 105, 120, 135 and 150 DAP respectively.

Among interactions, $P_{40}\times10^{-5}$M GA_3 gave maximum value at all stages, except 90 DAP, at which $P_{30}\times10^{-5}$M Kn gave significant maximum value, the value for $P_{40}\times10^{-5}$M GA_3 was equalled by that for $P_{40}\times10^{-5}$M Kn at 120 DAP. Significant minimum value was given by the control ($P_0\times W_0$) at all stages in comparison with the control. The increase in leaf area due to $P_{40}\times10^{-5}$M GA_3 was 117.26, 184.97, 66.65, 46.01 and 46.35 per cent at 90, 105, 120, 135 and 150 DAP respectively (Table 88).

4.6.1.4 Leaf area ratio

Application of P_{30} proved best at all stages except 150 DAP at which a non-significant effect of phosphorus was observed. The increase in leaf area ratio resulted from the application of P_{30} was 7.84, 12.20, 5.37 and 7.03 per cent over the control at 90, 105, 120, 135 and 150 DAP respectively.

As far as effect of phytohormone was concerned, all sprayed concentrations of phytohormone were equally effective at 90, 135 and 150 DAP. However 10^{-5}M Kn and 10^{-4}M GA_3 at 105 DAP, and also with 10^{-5}M GA_3 at 120 DAP being at par gave maximum values. Significant minimum value was recorded for the water-sprayed control (W_0) at all stages except 105 DAP, at which the minimum value for the control was at par with that for 10^{-5}M GA_3 and 10^{-6}M Kn. The increase in leaf area ratio due to 10^{-5}M Kn was 14.59, 4.25, 15.85, 11.21 and 13.71 per cent and due to 10^{-5}M GA_3, 17.08, 0.98, 18.44, 11.76 and 12.46 over the water-sprayed control at 90, 105, 120, 135 and 150 DAP respectively.

Interaction effect was found non-significant at all stages (Table 89).

4.6.1.5 Specific leaf area

Of phosphorus treatments, P_{30} proved best at all samplings. The control (P_0) and P_{20} being at par gave minimum value at all stages, except 120 DAP, at which they differ significantly. The per cent increase in specific leaf area due to P_{30} over the control was 5.45, 9.52, 7.04, 3.81 and 5.07 at 90, 105, 120, 135 and 150 DAP respectively.

Table 88. Effect of soil-applied phosphorus and leaf-applied phytohormones and of their interaction on leaf area (cm^2 $plant^{-1}$) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose P kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
P_0	423	729	718	753	802	692	938	1943	1956	1995	2176	1802
P_{20}	507	774	751	784	801	717	1446	2173	2040	2260	2258	2035
P_{30}	716	891	858	840	966	854	1626	2328	2472	2478	2618	2304
P_{40}	602	919	898	861	846	825	1542	2673	2259	2453	2448	2275
Mean	562	828	807	810	854		1388	2279	2182	2297	2375	
	120 DAP						135 DAP					
P_0	2984	4065	4084	3841	3913	3777	5534	7204	7073	7221	7299	6866
P_{20}	3228	4260	4230	4135	4448	4040	5672	7465	7154	7215	7535	7006
P_{30}	3626	4555	4479	4552	4687	4380	6238	7846	7455	7837	7668	7409
P_{40}	3410	4973	3979	4201	4946	4302	6009	8080	7509	7519	7843	7392
Mean	3287	4457	4370	4182	4499		5888	7649	7298	7448	7586	
	150 DAP											
P_0	5430	7004	6865	6962	7099	6672						
P_{20}	5429	7250	7153	7040	7176	6810						
P_{30}	5917	7620	7329	7533	7551	7190						
P_{40}	5646	7947	7256	7215	7690	7151						
Mean	5605	7455	7151	7188	7379							

CD at 5%					
	90	105	120	135	150
Phosphorus	9	17	22	21	23
Phytohormone	10	19	24	23	26
Interaction	20	38	48	46	52

Table 89. Effect of soil-applied phosphorus and leaf-applied phytohormones and of their interaction on leaf area ratio (cm^2g^{-1}) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose P kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
P_0	267.72	339.07	312.17	331.72	336.97	317.53	434.26	559.94	587.35	590.24	623.49	559.06
P_{20}	268.25	335.06	327.95	345.37	314.12	318.31	602.50	615.58	521.74	619.18	556.16	583.03
P_{30}	325.45	362.20	345.97	305.45	372.97	342.41	637.64	600.00	655.70	604.39	638.54	627.25
P_{40}	292.23	314.29	365.04	345.78	297.89	323.05	673.36	595.22	672.32	569.14	629.31	627.87
Mean	288.41	337.66	337.78	332.08	330.49		586.94	592.69	609.28	595.74	611.88	
	120 DAP						135 DAP					
P_0	525.35	691.33	671.71	629.67	558.20	615.25	570.52	643.79	580.23	629.55	622.25	609.27
P_{20}	539.31	690.44	667.19	615.33	640.00	630.45	567.20	641.87	593.20	637.37	642.37	616.40
P_{30}	609.41	663.03	652.92	650.29	665.77	648.28	595.80	672.32	665.62	669.83	657.07	652.13
P_{40}	596.15	644.17	658.77	566.17	736.01	640.25	584.53	632.73	677.71	613.30	658.52	631.36
Mean	567.56	672.24	662.65	615.37	657.50		579.51	647.68	629.19	637.51	645.05	
	150 DAP											
P_0	583.24	649.72	577.34	625.52	635.54	614.27						
P_{20}	568.48	630.43	605.67	636.53	639.00	616.02						
P_{30}	571.69	659.74	661.46	650.52	653.77	639.44						
P_{40}	577.89	648.20	686.47	627.39	688.45	645.68						
Mean	575.33	647.02	632.74	634.99	654.19							

CD at 5%					
	90	105	120	135	150
Phosphorus	9.17	10.88	17.00	20.77	NS
Phytohormone	10.28	12.16	19.00	21.73	47.06
Interaction	NS	NS	NS	NS	NS

With regard to phytohormones, 10^{-5}M GA_3 and 10^{-5}M Kn being at par in effect gave maximum value at all stages of sampling, however their value was at par with that for 10^{-6}M Kn at 135 DAP and with that for 10^{-4}M GA_3 at 150 DAP. The effect of water-sprayed control (W_0) was significantly lowest at all stages. Increase in specific leaf area due to 10^{-5}M GA_3 was 29.53, 38.83, 26.13, 20.22 and 23.62 per cent and due to 10^{-5}M Kn, 24.83, 44.08, 26.46, 21.37 and 23.04 per cent over the water-sprayed control at 90, 105, 120, 135 and 150 DAP respectively.

The interaction effect of phosphorus and leaf-applied phytohormones was non-significant (Table 90).

4.6.1.6 Leaf dry weight

The increasing doses of phosphorus upto P_{30} increased leaf dry weight linearly, thereafter a decrease in the weight was noted at all stages studied. Significant minimum value was recorded for the control (P_0). The per cent increase in leaf dry weight due to P_{30} over the control was 15.79, 16.48, 8.58, 3.34 and 2.13 at 90, 105, 120, 135 and 150 DAP respectively.

Among phytohormones, 10^{-5}M Kn at 90, 105 and 120 DAP and 10^{-5}M GA_3 at 135 and 150 DAP gave maximum values. However, the value for 10^{-5}M Kn was equalled by that for 10^{-6}M Kn at 90 DAP, by those for 10^{-6}M Kn and 10^{-5}M GA_3 at 105 DAP and by that for 10^{-5}M GA_3 at 120 DAP. The water-sprayed control (W_0) gave significant minimum value at each sampling stage. Treatment 10^{-5}M Kn gave 23.08, 20.11, 5.35, 7.68 and 6.56 and 10^{-5}M GA_3, 17.52, 20.11, 4.77, 8.90 and 7.79 per cent higher value for leaf dry weight than the water-sprayed control at 90, 105, 120, 135 and 150 DAP respectively.

Regarding interaction effect, $P_{40}\times10^{-5}$M GA_3 gave maximum values at all stages, however its effect was at par with that of $P_{40}\times10^{-5}$M Kn and $P_{30}\times10^{-5}$M Kn at 90 DAP, with that of $P_{30}\times10^{-6}$M Kn and $P_{30}\times10^{-5}$M Kn at 105 DAP and with that of $P_{30}\times10^{-6}$M Kn at 120 DAP. The control ($P_0\times W_0$) gave significant minimum values at all stages. Treatment $P_{40}\times10^{-5}$M GA_3 increased leaf dry weight by 44.44, 49.02, 24.05, 23.42 and 20.70 per cent over the control at 90, 105, 120, 135 and 150 DAP respectively (Table 91).

Table 90. Effect of soil-applied phosphorus and leaf-applied phytohormones and of their interaction on specific leaf area (cm^2g^{-1}) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose P kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
P_0	204.34	296.34	306.84	284.13	286.43	275.62	306.54	514.02	531.52	539.19	549.49	493.35
P_{20}	216.67	301.17	279.18	299.24	284.04	276.06	426.55	564.42	512.56	551.22	541.49	525.50
P_{30}	263.24	301.01	310.87	267.52	310.61	290.65	419.07	542.66	573.54	563.18	603.23	540.34
P_{40}	246.72	307.36	320.71	288.93	281.06	288.96	428.33	573.03	532.78	593.95	582.86	545.14
Mean	232.74	301.47	290.18	284.96	290.54		395.12	548.53	533.10	561.83	569.27	
	120 DAP						135 DAP					
P_0	491.60	594.30	586.78	555.06	556.61	556.87	531.09	649.59	628.15	637.90	668.34	623.01
P_{20}	464.09	591.67	599.15	592.41	606.82	570.83	541.22	635.86	604.73	664.96	665.64	622.49
P_{30}	504.31	613.88	612.72	623.56	625.77	596.05	573.87	728.51	658.57	630.00	642.72	646.73
P_{40}	490.65	660.42	544.32	587.55	677.53	592.09	551.79	628.30	703.75	686.04	691.01	652.18
Mean	487.66	615.07	585.74	589.65	616.68		549.49	660.57	648.80	654.73	666.93	
	150 DAP											
P_0	525.15	653.36	631.55	644.63	645.36	620.01						
P_{20}	527.09	625.54	618.77	648.85	632.80	610.61						
P_{30}	554.54	728.90	724.21	615.94	657.75	656.27						
P_{40}	534.15	638.78	707.21	678.74	698.46	651.47						
Mean	535.23	661.64	670.44	647.04	658.59							

CD at 5%					
	90	105	120	135	150
Phosphorus	9.03	10.04	13.80	15.74	13.39
Phytohormone	11.09	11.23	14.25	16.42	13.80
Interaction	NS	NS	NS	NS	NS

Table 91. Effect of soil-applied phosphorus and leaf-applied phytohormones and of their interaction on leaf dry weight (g plant^{-1}) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose P kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
P_0	2.07	2.46	2.48	2.65	2.70	2.47	3.06	3.78	3.68	3.70	3.96	3.64
P_{20}	2.34	2.57	2.69	2.62	2.82	2.61	3.39	3.65	3.98	4.10	4.17	3.90
P_{30}	2.50	2.96	2.96	2.91	2.98	2.86	3.88	4.29	4.31	4.40	4.34	4.24
P_{40}	2.44	2.99	2.97	2.98	3.01	2.88	3.60	4.56	4.24	4.13	4.20	4.15
Mean	2.34	2.75	2.78	2.79	2.88		3.48	4.12	4.05	4.08	4.18	
	120 DAP						135 DAP					
P_0	6.07	6.84	6.96	6.92	7.03	6.76	10.42	11.09	11.26	11.32	11.37	11.09
P_{20}	6.74	7.20	7.06	6.98	7.33	7.06	10.48	11.74	11.83	10.85	11.32	11.24
P_{30}	7.19	7.42	7.31	7.30	7.49	7.34	10.87	10.77	11.32	12.42	11.93	11.46
P_{40}	6.95	7.53	7.31	7.15	7.30	7.25	10.89	12.86	10.67	10.96	11.35	11.34
Mean	6.92	7.25	7.16	7.09	7.29		10.67	11.62	11.27	11.39	11.49	
	150 DAP											
P_0	10.34	10.72	10.87	10.80	11.00	10.78						
P_{20}	10.48	11.59	11.56	10.85	11.34	10.84						
P_{30}	10.67	10.57	10.12	12.23	11.48	11.01						
P_{40}	10.57	12.48	10.26	10.63	11.01	10.99						
Mean	10.52	11.34	10.70	11.13	11.21							

	CD at 5%				
	90	105	120	135	150
Phosphorus	0.07	0.11	0.04	0.15	0.10
Phytohormone	0.09	0.12	0.06	0.17	0.11
Interaction	0.16	0.24	0.10	0.32	0.23

4.6.1.7 Specific leaf weight

The control (P_0) gave maximum value for this parameter at all stages. The decrease in specific leaf weight due to P_{30} in comparison to the control was 10.71, 12.83 and 6.51 at 90, 105 and 120 DAP, respectively.

Pertaining to effect of phytohormones, the water-sprayed control (W_0) gave significant maximum values at all stages. All spray concentrations of phytohormones, excluding the control (W_0), were equally effective at all stages, except 150 DAP, at which all spayed treatments were non-significant in effect.

The combined effect of soil-applied phosphorus and leaf-applied phytohormones was found non-significant at all stages (Table 92).

4.6.1.8 Stem dry weight

For phosphorus treatments, the value recorded for P_{30} equalled ~~by~~ to that ~~for~~ by P_{40} was the maximum at all stages. On the other hand, the control (P_0) gave a minimum value at all stages. The per cent increase in stem dry weight due to P_{30} over the control was 16.82, 16.09, 9.59, 3.73 and 3.31 per cent at 90, 105, 120, 135 and 150 DAP, respectively.

Regarding phytohormones, 10^{-5}M Kn gave significant ~~maximum~~ high values at 90, 105 and 120 DAP while at 135 and 150 DAP 10^{-5}M GA_3 gave ~~maximum~~ high values which was equalled by that for 10^{-5}M Kn. The water-sprayed control (W_0) gave significant minimum values at all stages. The increase in stem dry weight due to 10^{-5}M Kn was 33.33, 65.53, 19.69, 16.32 and 13.74 per cent and due to 10^{-5}M GA_3 was 25.76, 62.55, 15.03, 16.91 and 14.74 per cent over the water-sprayed control at 90, 105, 120, 135 and 150 DAP, respectively.

Pertaining to interactions, $P_{40}\times10^{-5}$M GA_3 gave maximum values at all stages but the value was equalled by those for $P_{40}\times10^{-5}$M Kn and $P_{30}\times10^{-6}$M Kn at 90 DAP, and that for $P_{40}\times10^{-6}$M Kn at 105 DAP.

Significant minimum value was registered for the control ($P_0\times W_0$) at all stages. The increase in stem dry weight due to $P_{40}\times10^{-5}$M GA_3 compared with control was 81.65, 103.24, 35.91, 31.64 and 31.69 per cent at 90, 105, 120, 135 and 150 DAP, respectively (Table 93).

Table 92. Effect of soil-applied phosphorus and leaf-applied phytohormones and of their interaction on specific leaf weight (mg cm^{-2}) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose P kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
P_0	4.89	3.37	3.45	3.52	3.37	3.72	3.26	1.95	1.88	1.82	1.66	2.11
P_{20}	4.61	3.32	3.58	3.34	3.52	3.67	2.34	1.77	1.95	1.81	1.85	1.94
P_{30}	3.49	3.32	3.45	3.46	3.08	3.36	2.35	1.84	1.74	1.78	1.66	1.87
P_{40}	4.09	3.25	3.31	3.46	3.56	3.53	2.33	1.74	1.88	1.68	1.72	1.87
Mean	4.26	3.32	3.45	3.45	3.38		2.57	1.82	1.86	1.77	1.72	
	120 DAP						135 DAP					
P_0	2.03	1.68	1.70	1.80	1.80	1.80	1.88	1.54	1.59	1.57	1.56	1.63
P_{20}	2.15	1.69	1.67	1.69	1.65	1.77	1.85	1.57	1.65	1.50	1.50	1.61
P_{30}	1.98	1.63	1.63	1.60	1.60	1.69	1.74	1.37	1.52	1.58	1.56	1.55
P_{40}	2.04	1.51	1.83	1.70	1.48	1.71	1.81	1.59	1.42	1.46	1.45	1.55
Mean	2.05	1.63	1.71	1.70	1.63		1.82	1.52	1.54	1.53	1.52	
	150 DAP											
P_0	1.90	1.53	1.58	1.55	1.55	1.62						
P_{20}	1.93	1.59	1.62	1.64	1.58	1.67						
P_{30}	1.80	1.38	1.34	1.62	1.52	1.53						
P_{40}	1.87	1.57	1.42	1.47	1.43	1.55						
Mean	1.88	1.52	1.49	1.57	1.52							

	CD at 5%				
	90	105	120	135	150
Phosphorus	0.12	0.15	0.08	NS	NS
Phytohormone	0.14	0.17	0.10	0.20	NS
Interaction	NS	NS	NS	NS	NS

Table 93. Effect of soil-applied phosphorus and leaf-applied phytohormones and of their interaction on stem dry weight (g plant^{-1}) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose P kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
P_0	1.58	2.15	2.30	2.27	2.38	2.14	2.16	3.47	3.33	3.38	3.49	3.17
P_{20}	1.89	2.31	2.29	2.27	2.55	2.26	2.40	3.53	3.91	3.75	4.06	3.53
P_{30}	2.20	2.46	2.48	2.75	2.59	2.50	2.55	3.88	3.77	4.10	4.10	3.68
P_{40}	2.06	2.87	2.46	2.49	2.84	2.54	2.29	4.39	3.36	4.31	3.89	3.65
Mean	1.98	2.45	2.43	2.45	2.64		2.35	3.82	3.59	3.80	3.89	
	120 DAP						135 DAP					
P_0	5.68	5.88	6.08	6.10	7.01	6.15	9.70	11.19	12.19	11.47	11.73	11.26
P_{20}	5.80	6.17	6.34	6.72	6.95	6.40	10.00	11.63	12.06	11.32	11.73	11.35
P_{30}	5.95	6.87	6.86	7.00	7.04	6.74	10.47	11.67	11.20	11.70	11.67	11.68
P_{40}	5.72	7.72	6.04	7.42	6.72	6.72	10.28	12.77	11.08	12.26	11.91	11.66
Mean	5.79	6.66	6.33	6.81	6.93		10.11	11.82	11.63	11.69	11.76	
	150 DAP											
P_0	9.31	10.78	11.89	11.13	11.17	10.86						
P_{20}	9.55	11.50	11.81	11.06	11.23	11.03						
P_{30}	10.35	11.55	11.08	11.58	11.55	11.22						
P_{40}	9.77	12.26	10.57	11.50	11.74	11.17						
Mean	10.04	11.52	11.34	11.32	11.42							

CD at 5%					
	90	105	120	135	150
Phosphorus	0.08	0.04	0.07	0.05	0.08
Phytohormone	0.09	0.05	0.08	0.06	0.09
Interaction	0.18	0.09	0.17	0.11	0.17

4.6.1.9 Aboveground plant dry weight

Application of P_{30} proved best at all stages for this parameter. Treatment P_{30} gave 21.24, 33.58, 20.54, 18.96 and 18.97 per cent higher value for aboveground plant dry weight than the control at 90, 105, 120, 135 and 150 DAP, respectively.

With regard to phytohormone treatments, 10^{-5}M Kn at 90, 105, 120 and 135 DAP and 10^{-5}M GA_3 at 150 DAP gave significant maximum value, however at 135 DAP, the value for 10^{-5}M GA_3 was equal to that for 10^{-5}M Kn. Significant minimum value was registered for the water-sprayed control (W_0) at all stages. The increase in aboveground plant dry weight due to 10^{-5}M Kn was 33.89, 34.75, 13.54, 11.58 and 11.03 and due to 10^{-5}M GA_3 was 28.44, 32.08, 10.50, 11.67 and 11.52 per cent over the water-sprayed control at 90, 105, 120, 135 and 150 DAP, respectively.

Regarding interactions, $P_{40}\times10^{-5}$M GA_3 gave significant maximum values at all stages, however its value was at par with that for $P_{40}\times10^{-5}$M Kn at 90 DAP. Significant minimum value was recorded for the control ($P_0\times W_0$). Increase in aboveground plant dry weight due to $P_{40}\times10^{-5}$M GA_3 over the control was 92.63, 107.72, 50.94, 44.78 and 45.35 per cent at 90, 105, 120, 135 and 150 DAP, respectively (Table 94).

4.6.1.10 Underground plant fresh weight

Among treatments of phosphorus, P_{30} proved best at all stages. The significant minimum value was registered for the control (P_0) at all samplings. In comparison with the control the per cent increase in underground plant fresh weight resulted from the application of P_{30} was 28.21, 27.08, 18.14, 36.13 and 36.84 per cent at 90, 105, 120, 135 and 150 DAP, respectively.

With respect to phytohormone, 10^{-5}M Kn gave significant maximum value at all stages except 90 DAP, at which it was equal to 10^{-6}M Kn in effect. The water-sprayed control (W_0) gave significant minimum values at all samplings. Treatment 10^{-5}M Kn gave 45.42, 74.17, 42.92, 40.13 and 44.34 per cent more underground plant fresh weight than the water-sprayed control at 90, 105, 120, 135 and 150 DAP, respectively.

Regarding interaction effect, $P_{30}\times10^{-6}$M Kn gave maximum values at all samplings, however its effect was at par with that of $P_{40}\times10^{-5}$M Kn and $P_{30}\times10^{-5}$M Kn

Table 94. Effect of soil-applied phosphorus and leaf-applied phytohormones and of their interaction on aboveground plant dry weight (g plant^{-1}) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose P kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
P_0	3.26	4.69	5.01	4.92	5.10	4.61	5.22	6.98	7.29	6.90	7.12	6.70
P_{20}	4.02	4.88	4.98	4.89	5.37	4.83	5.79	7.28	7.53	7.80	8.23	7.33
P_{30}	5.05	5.81	5.38	5.89	5.83	5.59	7.47	8.82	8.85	10.13	9.47	8.95
P_{40}	4.56	6.28	5.31	5.53	6.23	5.51	6.96	10.53	8.16	9.00	9.45	8.82
Mean	4.22	5.42	5.17	5.31	5.65		6.36	8.40	7.96	8.46	8.57	
	120 DAP						135 DAP					
P_0	11.76	12.73	13.04	13.02	14.44	13.00	19.56	21.71	22.88	22.22	22.53	21.78
P_{20}	12.87	13.88	13.95	13.71	14.70	13.79	21.23	23.50	24.35	22.70	23.68	23.09
P_{30}	15.34	15.38	15.57	17.02	16.62	15.67	24.48	25.98	24.46	27.47	27.14	25.91
P_{40}	14.09	17.75	14.41	16.12	15.64	15.60	23.85	28.32	24.46	26.30	26.08	25.80
Mean	13.52	14.94	14.24	14.97	15.35		22.28	24.88	24.04	24.67	24.86	
	150 DAP											
P_0	19.36	21.50	22.76	22.09	22.36	21.61						
P_{20}	21.09	23.22	23.82	22.54	23.60	22.81						
P_{30}	24.35	25.87	24.36	27.39	26.57	25.71						
P_{40}	23.72	28.14	24.30	25.55	25.74	25.49						
Mean	22.13	24.68	23.81	24.39	24.57							

	CD at 5%				
	90	105	120	135	150
Phosphorus	0.07	0.06	0.06	0.04	0.06
Phytohormone	0.08	0.07	0.07	0.05	0.07
Interaction	0.16	0.13	0.16	0.10	0.15

at 90 DAP, with that of $P_{40}\times10^{-5}$M GA_3 and $P_{40}\times10^{-5}$M Kn at 105 DAP, with that of $P_{40}\times10^{-5}$M GA_3, $P_{30}\times10^{-5}$M Kn and $P_{40}\times10^{-5}$M Kn at 120 DAP, with that of $P_{40}\times10^{-5}$M GA_3 at 135 DAP. The value given by the control ($P_0\times W_0$) was significantly lowest at all samplings. The increase in underground plant fresh weight due to $P_{30}\times10^{-6}$M Kn over the control was 116.64, 115.57, 67.67, 108.05 and 113.84 per cent at 90, 105, 120, 135 and 150 DAP, respectively (Table 95).

4.6.1.11 Underground plant dry weight

Treatment P_{30} gave maximum value at all stages, however its effect was at par with that of P_{40} at 90, 135 and 150 DAP. Minimum value was recorded for control (P_0). Treatment P_{30} gave 29.01, 27.18, 18.26, 36.12 and 36.83 per cent higher value as compared with the control at 90, 105, 120, 135 and 150 DAP, respectively.

Regarding phytohormones, 10^{-5}M Kn gave maximum value at all stages, however its effect was at par with that of 10^{-6}M Kn at 90, 120 and 135 DAP. Minimum value was recorded for the water-sprayed control (W_0) at all sampling stages. The per cent increase in underground plant dry weight due to 10^{-5}M Kn was 45.70, 73.80, 42.95, 40.13 and 44.24 in comparison with the water-sprayed control at 90, 105, 120, 135 and 150 DAP, respectively.

Among interactions, $P_{30}\times10^{-6}$M Kn gave maximum value at all stages, however its value was equalled by that for $P_{40}\times10^{-5}$M Kn and $P_{30}\times10^{-5}$M Kn at 90 DAP, by that for $P_{40}\times10^{-5}$M GA_3 at 105 and 135 DAP and by that for $P_{40}\times10^{-5}$M GA_3, $P_{30}\times10^{-5}$M Kn, $P_{40}\times10^{-5}$M Kn, $P_{20}\times10^{-5}$M Kn and $P_{40}\times10^{-5}$M GA_3 at 120 DAP. Minimum value was recorded for the control ($P_0\times W_0$) at all stages. The increase in underground plant dry weight due to $P_{30}\times10^{-6}$M Kn over the control was 116.30, 146.82, 67.83, 108.23 and 113.92 per cent at 90, 105, 120, 135 and 150 DAP, respectively (Table 96).

4.6.2 Physiological characteristics

4.6.2.1 Photosynthetic characteristics

The effect of phosphorus and phytohormones, alone as well as in combination, on various photosynthetic characteristics was significant at all stages studied except 150 DAP, at which chlorophyll harvest was found non-significant (Table 97-101).

Table 95. Effect of soil-applied phosphorus and leaf-applied phytohormones and of their interaction on underground plant fresh weight (g plant^{-1}) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose P kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
P_0	4.15	5.20	4.73	7.63	7.90	5.92	5.47	9.20	8.55	10.21	12.93	9.27
P_{20}	5.47	6.78	6.07	8.00	8.25	6.91	7.58	10.15	8.73	11.90	13.00	10.07
P_{30}	6.76	7.37	6.37	8.97	8.48	7.59	8.77	12.40	9.35	13.98	13.17	11.78
P_{40}	6.35	7.33	6.73	8.43	8.65	7.57	8.38	13.63	9.63	12.42	13.48	11.26
Mean	5.68	6.67	5.96	8.26	8.32		7.55	11.34	9.06	12.13	13.15	
	120 DAP						135 DAP					
P_0	11.63	12.87	12.83	18.73	19.18	15.05	14.78	15.67	15.32	26.62	27.27	19.93
P_{20}	13.37	14.10	14.02	18.82	19.20	15.90	20.43	24.31	20.03	26.82	27.54	23.83
P_{30}	15.05	17.08	15.52	19.50	19.38	17.78	24.53	25.90	24.31	30.75	30.17	27.13
P_{40}	13.91	19.43	14.72	19.00	19.37	16.82	22.30	30.60	24.18	29.00	29.97	27.05
Mean	13.49	15.87	14.27	19.01	19.28		20.51	24.12	20.96	28.30	28.74	
	150 DAP											
P_0	14.23	15.00	15.01	25.23	27.01	19.30						
P_{20}	17.17	23.35	19.83	25.55	27.16	22.72						
P_{30}	23.48	25.20	23.35	30.43	29.58	26.41						
P_{40}	23.23	29.33	21.03	28.50	29.03	26.22						
Mean	19.53	23.22	19.81	27.43	28.19							

CD at 5%					
	90	105	120	135	150
Phosphorus	0.23	0.23	0.13	0.25	0.22
Phytohormone	0.26	0.26	0.14	0.28	0.24
Interaction	0.51	0.53	0.29	0.56	0.48

Table 96. Effect of soil-applied phosphorus and leaf-applied phytohormones and of their interaction on underground plant dry weight (g plant^{-1}) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose P kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
P_0	0.92	1.15	1.05	1.69	1.75	1.31	1.26	2.04	1.90	2.27	2.87	2.06
P_{20}	1.22	1.51	1.35	1.78	1.83	1.54	1.68	2.25	1.94	2.42	2.89	2.24
P_{30}	1.50	1.64	1.41	1.99	1.88	1.69	1.95	2.76	2.08	3.11	2.93	2.62
P_{40}	1.41	1.63	1.49	1.87	1.92	1.68	1.86	3.03	2.14	2.76	2.99	2.50
Mean	1.27	1.48	1.33	1.83	1.85		1.68	2.52	2.01	2.64	2.92	
	120 DAP						135 DAP					
P_0	2.58	2.86	2.85	4.16	4.26	3.34	3.28	3.48	3.40	5.91	6.06	4.43
P_{20}	2.97	3.13	3.12	4.18	4.27	3.53	4.54	5.40	4.45	5.96	6.12	5.29
P_{30}	3.34	3.80	3.45	4.33	4.31	3.95	5.45	5.76	5.40	6.83	6.70	6.03
P_{40}	3.09	4.32	3.27	4.22	4.30	3.74	4.96	6.80	5.37	6.44	6.66	6.01
Mean	2.98	3.53	3.17	4.24	4.26		4.56	5.36	4.66	6.29	6.39	
	150 DAP											
P_0	3.16	3.33	3.36	5.61	6.00	4.29				CD at 5%		
P_{20}	3.82	5.19	4.41	5.68	6.04	5.03			90	105	120	135	150
P_{30}	5.22	5.60	5.19	6.76	6.57	5.87	Phosphorus		0.05	0.05	0.03	0.04	0.05
P_{40}	5.16	6.52	4.67	6.33	6.45	5.83	Phytohormone		0.06	0.06	0.04	0.05	0.06
Mean	4.34	5.16	4.41	6.09	6.26		Interaction		0.11	0.11	0.09	0.12	0.11

4.6.2.1.1 Chlorophyll content

Of phosphorus treatments, maximum and minimum values were recorded for P_{30} and the control (P_0) respectively at all stages. The chlorophyll content increased due to P_{30} in comparison with the control was 15.87, 24.82, 20.45, 14.29 and 14.22 per cent at 90, 105, 120, 135 and 150 DAP, respectively.

Regarding phytohormones, 10^{-5}M Kn at 90, 105 and 120 DAP and 10^{-5}M GA_3 at 150 DAP were found with significant maximum value. However, maximum value given by 10^{-5}M GA_3 at 135 DAP was equalled by that for 10^{-5}M Kn. The effect of water-sprayed control (W_0) was significantly lowest at all samplings. The increase in chlorophyll content due to 10^{-5}M Kn was 20.83, 14.79, 10.32, 5.44 and 6.61 per cent and due to 10^{-5}M GA_3 14.17, 12.68, 8.15, 6.28 and 7.49 per cent than the water-sprayed control at 90, 105, 120, 135 and 150 DAP, respectively.

Pertaining to interaction effect, $P_{40}\times10^{-5}$M GA_3 gave maximum value at all stages, however its effect was at par with that of $P_{30}\times10^{-6}$M Kn at all stages, however its effect was at par with that of $P_{30}\times10^{-6}$M Kn at all stages and also with that of $P_{30}\times10^{-4}$M GA_3 at 135 DAP. Moreover, significant minimum value was given by the control ($P_0\times W_0$) at all stages. Interaction of $P_{40}\times10^{-5}$M GA_3 gave 41.82, 60.00, 41.98, 27.96 and 34.52 per cent higher value for chlorophyll content than the control at 90, 105, 120, 135 and 150 DAP, respectively (Table 97).

4.6.2.1.2 Chlorophyll harvest per plant

Maximum and minimum value was recorded for P_{30} and control (P_0) respectively at all stages except 150 DAP, at which the data recorded was found non-significant. Treatment P_{30} gave 41.71, 58.52, 40.28 and 22.26 per cent higher value than the control for chlorophyll harvest at 90, 105, 120 and 135 DAP, respectively.

Among phytohormones, maximum significant values were recorded for 10^{-5}M Kn at 90, 105 and 120 DAP and for 10^{-5}M GA_3 at 135 DAP. Minimum significant value was registered for the water-sprayed control (W_0). The increase in chlorophyll harvest due to 10^{-5}M Kn was 77.99, 93.68, 50.73 and 37.48 per cent and due to 10^{-5}M GA_3 at 111.66, 83.99, 46.73 and 38.24 per cent over the water-sprayed control at 90,

Table 97. Effect of soil-applied phosphorus and leaf-applied phytohormones and of their interaction on chlorophyll content (mg g^{-1} fresh weight) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose P kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
P_0	1.10	1.23	1.29	1.28	1.41	1.26	1.20	1.40	1.50	1.37	1.40	1.37
P_{20}	1.17	1.25	1.36	1.26	1.42	1.29	1.32	1.43	1.57	1.49	1.56	1.47
P_{30}	1.37	1.45	1.38	1.54	1.50	1.45	1.62	1.66	1.66	1.90	1.76	1.72
P_{40}	1.17	1.56	1.40	1.43	1.50	1.41	1.54	1.92	1.59	1.55	1.80	1.68
Mean	1.20	1.37	1.36	1.38	1.45		1.42	1.60	1.58	1.58	1.63	
	120 DAP						135 DAP					
P_0	1.62	1.77	1.81	1.78	1.83	1.76	2.11	2.31	2.35	2.38	2.39	2.31
P_{20}	1.73	1.92	1.90	1.84	1.85	1.85	2.34	2.49	2.41	2.41	2.44	2.42
P_{30}	2.17	1.98	2.13	2.24	2.28	2.16	2.60	2.64	2.67	2.68	2.65	2.65
P_{40}	1.85	2.30	1.89	1.96	2.17	2.03	2.51	2.70	2.46	2.50	2.61	2.56
Mean	1.84	1.99	1.94	1.97	2.03		2.39	2.54	2.47	2.49	2.52	
	150 DAP											
P_0	1.97	2.20	2.20	2.27	2.28	2.18						
P_{20}	2.19	2.30	2.30	2.29	2.31	2.28						
P_{30}	2.50	2.60	2.40	2.63	2.58	2.49						
P_{40}	2.41	2.65	2.33	2.43	2.51	2.46						
Mean	2.27	2.44	2.31	2.41	2.42							

CD at 5%					
	90	105	120	135	150
Phosphorus	0.02	0.02	0.02	0.01	0.01
Phytohormone	0.03	0.02	0.03	0.02	0.01
Interaction	0.05	0.04	0.05	0.03	0.02

105, 120 and 135 DAP respectively. The effect at 150 DAP was found non-significant.

Pertaining to interactions, significant maximum values were registered for $P_{40}\times10^{-5}$M GA_3 at 105, 120 and 135 DAP, however at 90 DAP, $P_{40}\times10^{-5}$M GA_3 was at par with that of $P_{30}\times10^{-5}$M Kn. Significant minimum value was recorded for water-sprayed control ($P_0\times W_0$). Interaction $P_{40}\times10^{-5}$M GA_3 gave 208.39, 355.77, 136.61 and 86.83 per cent higher value in comparison with control at 90, 105, 120 and 135 DAP respectively. All interactions showed non-significant effect at 150 DAP (Table 98).

4.6.2.1.3 Photosynthetic rate

Increasing rates of phosphorus upto P_{30} enhanced the rate of photosynthesis, and the highest level i.e. P_{40} gave lower value than P_{30}. The treatment P_{30} increased rate of photosynthesis by 23.84, 20.31, 17.02, 15.25 and 13.72 per cent over the control at 90, 105, 120, 135 and 150 DAP respectively.

Among phytohormone treatments, 10^{-5}M Kn gave maximum values at 90, 105 and 120 DAP and 10^{-5}M GA_3, at 135 and 150 DAP. However, the maximum value for 10^{-5}M Kn at 90 DAP was equalled by those for 10^{-6}M Kn, and at 150 DAP, by that for 10^{-5}M GA_3. Significant minimum value was given by the water-sprayed control (W_0) at all stages. Treatment 10^{-5}M Kn gave 33.07, 25.16, 9.98, 7.43 and 8.06 per cent and 10^{-5}M GA_3, 24.73, 22.30, 6.07, 7.85 and 9.36 per cent higher value for photosynthetic rate than the water-sprayed control at 90, 105, 120, 135 and 150 DAP respectively.

Regarding interaction effect, $P_{40}\times10^{-5}$M GA_3 gave significant maximum value at all stages except 90 DAP, at which its maximum value was equalled by that for $P_{40}\times10^{-5}$M Kn. On the other hand, control ($P_0\times W_0$) gave significant minimum value at all samplings. The increase in rate of photosynthesis due to $P_{40}\times10^{-5}$M GA_3 in comparison with the control at 90, 105, 120, 135 and 150 DAP was 74.45, 86.86, 31.73, 26.66 and 28.92 per cent respectively (Table 99).

4.6.2.1.4 Stomatal conductance

Maximum values were recorded for P_{30} at all sampling stages, and the value was equalled by those for P_{40} at 120, 135 and 150 DAP. The control (P_0) gave significant minimum values at all stages. The stomatal conductance increased due to P_{30} compared

Table 98. Effect of soil-applied phosphorus and leaf-applied phytohormones and of their interaction on chlorophyll harvest (mg . cm^2) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose P kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
P_0	465	897	926	1062	1027	875	1126	2720	2934	2733	3046	2512
P_{20}	593	968	1021	988	1137	941	1909	3107	3203	3364	3526	3022
P_{30}	981	1292	1184	1294	1449	1240	2634	3864	4104	4708	4602	3982
P_{40}	704	1435	1257	1231	1269	1179	2375	5132	3592	3802	4406	3861
Mean	686	1148	1097	1148	1221		2011	3706	3458	3652	3895	
	120 DAP						135 DAP					
P_0	4834	7195	7699	6837	7161	6745	11677	16641	16621	17186	18162	16057
P_{20}	5411	8179	7760	7608	8229	7437	13272	18588	17241	17388	18385	16975
P_{30}	7868	9019	9540	10196	10686	9462	16219	20713	19905	21003	20320	19632
P_{40}	6308	11438	8858	8234	10732	9114	15083	21816	18472	18798	20470	19072
Mean	6105	8958	8464	8219	9202		14063	19440	18060	18594	19334	
	150 DAP											
P_0	10697	15409	15103	15804	16450	14693						
P_{20}	11890	16675	16452	16122	16724	15573						
P_{30}	14792	19812	17741	19812	19224	18276						
P_{40}	13607	21060	16906	17532	20055	17832						
Mean	12747	18239	16551	17318	18113							

	CD at 5%				
	90	105	120	135	150
Phosphorus	13	21	16	20	NS
Phytohormone	15	23	17	22	NS
Interaction	30	47	35	45	NS

Table 99. Effect of soil-applied phosphorus and leaf-applied phytohormones and of their interaction on photosynthetic rate (μ mol CO_2 $m^{-2}s^{-1}$) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose P kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
P_0	8.65	10.70	11.60	12.50	11.90	11.07	11.49	17.06	17.61	17.76	17.56	16.30
P_{20}	9.83	11.00	11.30	13.10	11.09	11.26	16.27	17.18	18.01	18.45	18.13	17.61
P_{30}	12.20	14.03	13.40	14.60	14.30	13.71	16.75	19.52	20.06	20.75	20.26	19.61
P_{40}	10.10	15.09	12.80	13.75	14.92	13.33	17.01	21.47	18.75	18.97	21.07	19.31
Mean	10.19	12.71	12.28	13.49	13.56		15.38	18.81	18.61	18.98	19.25	
	120 DAP						135 DAP					
P_0	22.09	23.15	24.15	23.82	25.49	23.74	28.84	31.14	30.10	30.52	30.50	30.22
P_{20}	23.51	24.48	24.81	25.14	26.09	24.81	29.80	31.58	32.43	30.82	31.22	31.17
P_{30}	26.79	27.45	27.78	28.77	28.11	27.78	33.24	34.36	34.50	36.09	36.00	34.83
P_{40}	25.80	29.10	26.84	27.12	28.44	27.46	31.99	36.53	32.57	33.88	35.00	34.07
Mean	24.55	26.04	25.89	26.21	27.00		30.97	33.40	32.06	32.83	33.27	
	150 DAP											
P_0	27.94	30.27	30.57	29.75	29.67	29.44						
P_{20}	29.04	30.95	30.63	30.01	30.84	30.13						
P_{30}	31.67	33.59	32.78	35.23	34.15	33.48						
P_{40}	30.99	36.02	31.36	32.08	34.60	33.01						
Mean	29.91	32.71	31.33	31.77	32.32							

	CD at 5%				
	90	105	120	135	150
Phosphorus	0.09	0.08	0.09	0.09	0.31
Phytohormone	0.10	0.09	0.10	0.10	0.35
Interaction	0.20	0.18	0.21	0.21	0.71

with the control was 11.33, 8.52, 4.20, 4.47 and 5.56 per cent at 90, 105, 120, 135 and 150 DAP, respectively.

Regarding phytohormones, 10^{-5}M Kn at 90, 105 and 120 DAP, and 10^{-5}M GA_3 at 135 and 150 DAP gave maximum value. However at 135 and 150 DAP, all phytohormone spray treatments were equal in effect. Significant minimum value was registered for the water-sprayed control (W_0) at all stages. The increase in stomatal conductance due to 10^{-5}M Kn at 90, 105 and 120 DAP was 15.45, 7.94, 2.34, 1.97 and 2.50 per cent, and due to 10^{-5}M GA_3, 10.57, 6.67, 1.30, 2.21 and 3.25 per cent over water-sprayed control at 90, 105, 120, 135 and 150 DAP, respectively.

With regard to interaction effect, $P_{40}\times10^{-5}$M GA_3 at 90, 105, 120, 135 and 150 DAP was found with maximum value. However at 90, 135 and 150 DAP, its value was equal to that for $P_{30}\times10^{-6}$M Kn and $P_{40}\times10^{-5}$M Kn and also for $P_{30}\times10^{-5}$M Kn at 120 DAP. On the other hand, the control ($P_0\times W_0$) showed significant lowest effect at all stages except 135 DAP, at which its value was equalled by that for $P_{20}\times W_0$. The per cent increase in stomatal conductance due to $P_{40}\times10^{-5}$M GA_3 over the control was 32.74, 22.45, 9.04, 8.61 and 11.20 per cent at 90, 105, 120, 135 and 150 DAP, respectively (Table 100).

4.6.2.1.5 Photosynthetic water use efficiency

Among nitrogen treatments, maximum and minimum value was registered for P_{30} and the control (P_0) respectively at all stages. Treatment P_{30} gave 11.78, 13.71, 12.33, 9.97 and 7.86 per cent increase in photosynthetic water use efficiency in comparison with the control at 90, 105, 120, 135 and 150 DAP, respectively.

With regard to phytohormones, 10^{-5}M Kn at 90, 105 and 120 DAP, and 10^{-5}M GA_3 at 135 and 150 DAP gave significant maximum values. On the other hand, the effect of water-sprayed control (W_0) was significantly lowest. The increase in photosynthetic water use efficiency due to 10^{-5}M Kn was 15.39, 14.67, 7.54, 8.83 and 12.04 per cent and due to 10^{-5}M GA_3, 27.11, 34.54, 11.45, 5.45 and 5.79 per cent over the water-sprayed control at 90, 105, 120, 135 and 150 DAP, respectively.

Regarding interaction effect, $P_{40}\times10^{-5}$M GA_3 gave significant maximum value at all stages except 135 DAP, at which its value was equalled by those for $P_{30}\times10^{-6}$M Kn and $P_{30}\times10^{-5}$M Kn. Significant minimum value was registered for the control

Table 100. Effect of soil-applied phosphorus and leaf-applied phytohormones and of their interaction on stomatal conductance (mol $m^{-2}s^{-1}$) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose P kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
P_0	0.223	0.251	0.264	0.273	0.270	0.256	0.294	0.320	0.327	0.319	0.327	0.317
P_{20}	0.244	0.257	0.261	0.258	0.280	0.260	0.319	0.322	0.329	0.335	0.330	0.327
P_{30}	0.270	0.285	0.283	0.295	0.290	0.285	0.328	0.342	0.345	0.350	0.347	0.344
P_{40}	0.246	0.296	0.277	0.285	0.295	0.280	0.320	0.360	0.336	0.337	0.355	0.336
Mean	0.246	0.272	0.271	0.278	0.284		0.315	0.336	0.335	0.338	0.340	
	120 DAP						135 DAP					
P_0	0.376	0.378	0.382	0.381	0.388	0.381	0.395	0.401	0.410	0.403	0.403	0.403
P_{20}	0.380	0.385	0.385	0.386	0.391	0.385	0.400	0.414	0.414	0.406	0.410	0.409
P_{30}	0.393	0.397	0.397	0.400	0.398	0.397	0.418	0.420	0.420	0.427	0.423	0.421
P_{40}	0.389	0.401	0.393	0.396	0.399	0.396	0.414	0.429	0.417	0.419	0.424	0.421
Mean	0.385	0.390	0.390	0.391	0.394		0.407	0.416	0.415	0.414	0.415	
	150 DAP											
P_0	0.384	0.403	0.405	0.399	0.395	0.396						
P_{20}	0.392	0.406	0.405	0.400	0.407	0.401						
P_{30}	0.415	0.416	0.415	0.425	0.418	0.418						
P_{40}	0.408	0.427	0.412	0.415	0.421	0.417						
Mean	0.400	0.413	0.409	0.410	0.410							

	CD at 5%				
	90	105	120	135	150
Phosphorus	0.001	0.001	0.001	0.002	0.003
Phytohormone	0.002	0.001	0.002	0.003	0.004
Interaction	0.003	0.002	0.003	0.005	0.007

($P_0 \times W_0$) at all samplings. The increase in photosynthetic water use efficiency due to $P_{40} \times 10^{-5}$M GA_3 was 31.43, 52.61, 23.52, 16.63 and 15.94 per cent compared with the control at 90, 105, 120, 135 and 150 DAP, respectively (Table 101).

4.6.2.2 Nutrient contents in plant

The effect of phosphorus and phytohormones alone or in combination on nutrient content was not significant at all stages, except individual effect of phosphorus on phosphorus content (Tables 102-104).

4.6.2.2.1 Nitrogen content

The effect of phosphorus and phytohormones as well as of their interaction was found to be non-significant on nitrogen content (Table 102).

4.6.2.2.2 Phosphorus content

Application of phosphorus gave significant effect on phosphorus content. Significant maximum and minimum values were recorded for P_{30} and the control (P_0) respectively at all samplings. In comparison with the control, the increase in phosphorus content due to P_{30} was 39.04, 35.29, 43.22, 37.32 and 45.29 at 90, 105, 120, 135 and 150 DAP, respectively.

Regarding phytohormones, it was noted that their effect was non-significant on phosphorus content at all stages.

With regard to interaction effect, phosphorus content was not affected by the interaction of phosphorus and phytohormones (Table 103).

4.6.2.2.3 Potassium content

Potassium content was not affected significantly by the phosphorus and phytohormones alone as well as in combination (Table 104).

4.6.2.3 Nutrient uptake

The effect of phosphorus and phytohormones alone and of their interaction on nutrient uptake was significant at all stages (Tables 105-107).

4.6.2.3.1 Nitrogen uptake

For phosphorus treatments, maximum value was recorded for P_{30} at all stages, and its value was equalled by that for P_{40} at 90, 105, 120 and 135 DAP. Significant minimum value was given by the control (P_0) at all stages, except 90 DAP, at which its value was equalled by that for P_{20}. The per cent increase in nitrogen uptake by P_{30}

Table 101. Effect of soil-applied phosphorus and leaf-applied phytohormones and of their interaction on photosynthetic water use efficiency (μ mol mol^{-1}) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose P kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
P_0	38.79	42.63	43.93	45.79	44.07	43.04	39.08	53.31	53.85	52.51	53.70	50.49
P_{20}	40.29	42.80	43.46	42.98	46.79	43.26	51.00	53.35	54.74	55.07	54.93	53.82
P_{30}	45.19	49.23	47.35	49.49	49.31	48.11	54.15	57.08	58.14	59.29	58.39	57.41
P_{40}	41.06	50.98	46.21	48.25	50.58	47.42	53.16	59.64	55.80	56.29	59.35	56.85
Mean	41.33	46.41	45.24	46.63	47.69		49.35	55.85	55.63	55.79	56.59	
	120 DAP						135 DAP					
P_0	58.75	61.24	63.22	62.52	65.70	62.29	73.01	77.66	76.70	75.73	75.68	75.24
P_{20}	61.87	63.58	64.44	65.13	66.73	64.35	74.50	76.28	77.96	75.91	76.15	76.16
P_{30}	68.17	69.14	69.97	71.92	70.63	69.97	79.52	81.81	82.14	85.12	85.11	82.74
P_{40}	66.32	72.57	68.29	68.48	71.28	69.39	77.27	85.15	78.10	80.86	82.55	80.96
Mean	63.78	66.63	66.48	67.01	68.59		76.08	80.23	78.73	79.41	80.09	
	150 DAP											
P_0	72.76	75.11	75.48	74.56	74.55	74.29						
P_{20}	74.08	76.23	75.63	75.02	75.77	75.14						
P_{30}	76.31	80.74	78.99	82.89	81.70	80.13						
P_{40}	75.96	84.36	76.12	77.30	82.19	79.19						
Mean	74.78	79.11	76.56	77.44	78.55							

	CD at 5%				
	90	105	120	135	150
Phosphorus	0.09	0.11	0.12	0.08	0.10
Phytohormone	0.10	0.12	0.13	0.09	0.11
Interaction	0.20	0.24	0.25	0.19	0.21

Table 102. Effect of soil-applied phosphorus and leaf-applied phytohormones and of their interaction on nitrogen content (%) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose P kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
P_0	3.22	3.21	3.12	3.09	3.01	3.13	2.91	2.86	2.78	2.77	2.64	2.79
P_{20}	3.06	3.08	3.09	3.24	3.29	3.15	2.62	2.72	2.81	2.89	2.83	2.77
P_{30}	3.18	3.04	3.24	3.14	3.04	3.12	2.91	2.71	2.94	2.74	2.72	2.80
P_{40}	3.00	3.10	3.20	3.10	3.10	3.10	2.80	2.90	2.60	2.70	3.00	2.80
Mean	3.16	3.12	3.16	3.14	3.11		2.81	2.79	2.78	2.77	2.79	
	120 DAP						135 DAP					
P_0	2.31	2.41	2.28	2.22	2.45	2.33	2.01	1.94	2.05	2.10	1.94	2.01
P_{20}	2.22	2.36	2.30	2.29	2.49	2.33	1.99	1.98	2.03	2.11	2.09	2.03
P_{30}	2.36	2.34	2.35	2.37	2.32	2.35	2.02	2.14	2.10	1.98	2.03	2.05
P_{40}	2.30	2.30	2.40	2.30	2.20	2.30	2.00	2.12	1.93	1.90	2.10	2.01
Mean	2.30	2.35	2.33	2.30	2.37		2.01	2.05	2.02	2.02	2.04	
	150 DAP											
P_0	1.88	1.82	1.69	1.84	1.76	1.80						
P_{20}	1.70	1.73	1.80	1.90	1.88	1.80						
P_{30}	1.84	1.90	1.96	1.80	1.83	1.87						
P_{40}	1.82	1.88	1.81	1.70	1.82	1.81						
Mean	1.81	1.83	1.82	1.82	1.82							

	CD at 5%				
	90	105	120	135	150
Phosphorus	NS	NS	NS	NS	NS
Phytohormone	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS

Table 103. Effect of soil-applied phosphorus and leaf-applied phytohormones and of their interaction on phosphorus content (%) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose P kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
P_0	0.347	0.340	0.345	0.327	0.340	0.333	0.286	0.305	0.324	0.298	0.318	0.306
P_{20}	0.410	0.386	0.396	0.370	0.376	0.408	0.335	0.315	0.411	0.302	0.275	0.328
P_{30}	0.468	0.457	0.470	0.466	0.465	0.465	0.424	0.408	0.385	0.405	0.435	0.411
P_{40}	0.432	0.462	0.421	0.476	0.454	0.449	0.370	0.410	0.303	0.415	0.402	0.362
Mean	0.414	0.411	0.409	0.410	0.409		0.354	0.360	0.356	0.355	0.357	
	120 DAP						135 DAP					
P_0	0.247	0.245	0.234	0.224	0.232	0.236	0.216	0.203	0.205	0.209	0.212	0.209
P_{20}	0.266	0.201	0.318	0.291	0.260	0.267	0.236	0.225	0.261	0.242	0.230	0.239
P_{30}	0.337	0.350	0.307	0.318	0.368	0.336	0.289	0.281	0.269	0.279	0.278	0.279
P_{40}	0.312	0.348	0.308	0.300	0.297	0.313	0.249	0.275	0.254	0.261	0.260	0.260
Mean	0.285	0.286	0.286	0.283	0.289		0.248	0.246	0.247	0.248	0.245	
	150 DAP											
P_0	0.170	0.168	0.187	0.178	0.181	0.170						
P_{20}	0.224	0.198	0.218	0.201	0.202	0.203						
P_{30}	0.247	0.226	0.224	0.258	0.254	0.237						
P_{40}	0.218	0.265	0.222	0.232	0.228	0.230						
Mean	0.215	0.214	0.208	0.208	0.215							

	CD at 5%				
	90	105	120	135	150
Phosphorus	0.17	0.21	0.19	0.13	0.21
Phytohormone	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS

Table 104. Effect of soil-applied phosphorus and leaf-applied phytohormones and of their interaction on potassium content (%) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose P kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
P_0	2.94	2.90	2.78	2.87	2.78	2.85	2.49	2.45	2.60	2.39	2.57	2.50
P_{20}	2.78	2.89	2.72	2.88	2.98	2.85	2.67	2.52	2.42	2.56	2.44	2.52
P_{30}	2.80	2.78	3.00	3.02	2.70	2.86	2.50	2.41	2.55	2.70	2.44	2.50
P_{40}	2.87	2.90	2.88	2.70	2.95	2.86	2.45	2.72	2.51	2.43	2.56	2.53
Mean	2.85	2.87	2.85	2.87	2.85		2.53	2.53	2.52	2.52	2.50	
	120 DAP						135 DAP					
P_0	2.33	2.22	2.25	2.06	2.42	2.26	1.80	1.82	1.86	1.88	1.82	1.84
P_{20}	2.05	2.24	2.14	2.21	2.37	2.20	1.88	1.92	1.95	1.81	1.90	1.89
P_{30}	2.26	2.27	2.31	2.35	2.14	2.27	1.90	1.79	1.74	1.98	2.01	1.88
P_{40}	2.25	2.36	2.16	2.19	2.40	2.27	1.91	2.01	1.89	1.90	1.83	1.91
Mean	2.22	2.21	2.21	2.20	2.21		1.87	1.89	1.86	1.89	1.89	
	150 DAP											
P_0	1.55	1.70	1.67	1.65	1.54	1.65						
P_{20}	1.60	1.65	1.68	1.74	1.66	1.67						
P_{30}	1.65	1.58	1.57	1.68	1.70	1.64						
P_{40}	1.50	1.76	1.65	1.60	1.71	1.64						
Mean	1.58	1.67	1.64	1.67	1.65							

	CD at 5%				
	90	105	120	135	150
Phosphorus	NS	NS	NS	NS	NS
Phytohormone	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS

was 21.53, 36.16, 25.50, 21.51 and 28.76 in comparison with the control at 90, 105, 120, 135 and 150 DAP, respectively.

Pertaining to phytohormones, 10^{-5}M Kn and 10^{-5}M GA_3 being at par in effect, gave maximum values at all stages, however their effect was also at par with that of 10^{-6}M Kn at 90, 105, 120 and 150 DAP. On the other hand, significant minimum value was given by the water-sprayed control (W_0). The increase in nitrogen uptake due to 10^{-5}M Kn at was 33.33, 34.64, 17.92, 13.65 and 11.72 per cent and due to 10^{-5}M GA_3, 28.03, 30.72, 13.68, 14.32 and 12.97 per cent over the water-sprayed control at 90, 105, 120, 135 and 150 DAP, respectively.

Regarding interaction effect, $P_{40}\times10^{-5}$M GA_3 gave maximum values at all stages, however its value was equalled by those for $P_{40}\times10^{-5}$M Kn and $P_{30}\times10^{-6}$M Kn at 90 DAP by that for $P_{40}\times10^{-5}$M Kn at 105 DAP and by that for $P_{30}\times10^{-6}$M Kn, $P_{30}\times10^{-5}$M Kn and $P_{40}\times10^{-6}$M Kn at 120 DAP. On the other hand, significant minimum value was registered for the control ($P_0\times W_0$) at all stages except 150 DAP at which 10^{-4}M GA_3 gave significantly minimum value. The per cent increase resulted from the application of $P_{40}\times10^{-5}$M GA_3 was 86.67, 100.66, 50.00, 52.17 and 45.33 over the control at 90, 105, 120, 135 and 150 DAP, respectively (Table 105).

4.6.2.3.2 Phosphorus uptake

Of phosphorus treatments, maximum and minimum value was given by P_{30} and the control (P_0), respectively. Treatment P_{30} gave 66.30, 78.51, 70.77, 51.44 and 62.67 per cent increase in phosphorus uptake over the control at 90, 105, 120, 135 and 150 DAP, respectively.

With regard to phytohormones, maximum value was registered for 10^{-5}M Kn at 90, 105 and 120 DAP and for 10^{-5}M GA_3 at 135 and 150 DAP. However, the value for 10^{-5}M GA_3 was equalled by that for 10^{-5}M Kn at 150 DAP, and also by that for 10^{-6}M Kn at 135 DAP. The value registered for the water-sprayed control (W_0) was significantly ~~minimum~~ lower at all samplings. Treatment 10^{-5}M Kn gave 31.05, 35.67, 14.45, 8.83 and 12.04 per cent and 10^{-5}M GA_3, 27.11, 34.54, 11.45, 11.40 and 12.04 per cent higher value than the water-sprayed control at 90, 105, 120, 135 and 150 DAP, respectively.

Table 105. Effect of soil-applied phosphorus and leaf-applied phytohormones and of their interaction on nitrogen uptake (mg plant^{-1}) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose P kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
P_0	105	151	156	152	156	144	152	198	203	191	188	187
P_{20}	123	150	154	158	177	152	152	198	212	225	233	208
P_{30}	161	177	174	185	177	175	217	234	260	278	258	249
P_{40}	137	196	170	174	193	174	195	305	212	243	284	248
Mean	132	169	164	167	176		179	234	222	234	241	
	120 DAP						135 DAP					
P_0	272	307	298	289	354	298	393	421	469	467	437	437
P_{20}	286	328	321	314	366	323	423	465	494	479	495	471
P_{30}	362	354	366	403	386	374	494	556	514	540	551	531
P_{40}	324	408	346	381	344	361	477	600	472	500	548	519
Mean	307	349	333	347	362		447	511	487	496	508	
	150 DAP											
P_0	364	391	305	407	393	372						
P_{20}	359	402	429	428	444	412						
P_{30}	448	492	477	493	486	479						
P_{40}	432	529	440	434	468	461						
Mean	401	453	337	441	448							

CD at 5%					
	90	105	120	135	150
Phosphorus	8	11	15	13	12
Phytohormone	10	13	17	14	13
Interaction	18	24	32	27	25

Regarding interaction effect, significant maximum values was recorded for $P_{40}\times10^{-5}$M GA_3 at all stages. Moreover, the control ($P_0\times W_0$) gave significant minimum values at all stages. The increase in phosphorus uptake due to $P_{40}\times10^{-5}$M GA_3 over the control was 156.73, 189.34, 112.63, 84.33 and 126.59 per cent at 90, 105, 120, 135 and 150 DAP, respectively (Table 106).

4.6.2.3.3 Potassium uptake

The maximum value was recorded for P_{30} and the value was equalled by that for P_{40} at all samplings. On the other hand, significant minimum values was given by the control (P_0) at all stages except 105 DAP, at which its minimum value was equalled by that for P_{20}. Treatment P_{30} gave 22.90, 34.52, 27.02, 23.75 and 19.37 per cent increase in potassium uptake over the control at 90, 105, 120, 135 and 150 DAP, respectively.

The values recorded for all phytohormone treatments were statistically equal at all stages except 120 DAP, at which 10^{-4}M GA_3 gave lower values than the other phytohormone containing treatments. The effect of the water-sprayed control (W_0) was significantly lowest at all stages, except 120 DAP, at which it was equalled by that for 10^{-4}M GA_3. The increase in potassium uptake due to 10^{-5}M Kn was 34.17, 34.16, 19.86, 12.68 and 15.76 per cent, and due to 10^{-5}M GA_3 was 25.83, 32.92, 15.49, 12.44 and 18.34 per cent over the water-sprayed control at 90, 105, 120, 135 and 150 DAP, respectively.

Regarding interaction effect, $P_{40}\times10^{-5}$M GA_3 gave maximum values at all stages, however its effect was at par with that of $P_{40}\times10^{-5}$M Kn, $P_{30}\times10^{-6}$M Kn and $P_{40}\times10^{-4}$M GA_3 at 90 DAP, with that of $P_{30}\times10^{-6}$M Kn at 105 and 135 DAP and also with that of $P_{40}\times10^{-5}$M Kn at 120 DAP. Minimum values was given by the control ($P_0\times W_0$) at all stages. In comparison with the control, increase in potassium uptake due to $P_{40}\times10^{-5}$M GA_3 was 89.58, 120.00, 52.92, 61.65 and 65.00 per cent at 90, 105, 120, 135 and 150 DAP (Table 107).

4.6.3 Yield characteristics

Effect of phosphorus and phytohormone alone as well as in combination on various yield characteristics was significant at all stages (Tables 108-114).

Table 106. Effect of soil-applied phosphorus and leaf-applied phytohormones and of their interaction on phosphorus uptake (mg plant^{-1}) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose P kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
P_0	11.30	15.94	17.28	16.09	17.61	15.64	14.92	21.29	23.62	20.56	22.64	20.61
P_{20}	16.50	18.84	19.72	18.09	20.19	18.67	19.40	22.93	30.94	23.56	22.63	23.89
P_{30}	23.60	26.60	25.29	27.45	27.11	26.01	31.67	35.99	34.07	41.03	41.19	36.79
P_{40}	19.70	29.01	22.36	26.32	28.28	25.13	25.75	43.17	24.72	37.35	37.99	33.80
Mean	17.78	22.60	21.16	21.99	23.30		22.93	30.85	28.34	30.68	31.11	
	120 DAP						135 DAP					
P_0	29.05	31.19	30.51	31.77	33.50	31.20	42.25	44.07	45.67	46.44	47.76	45.24
P_{20}	34.23	27.90	44.36	39.90	38.22	36.92	50.10	52.88	63.55	54.93	54.46	55.18
P_{30}	49.47	53.83	47.80	54.12	61.16	53.28	70.74	73.00	65.80	76.64	75.45	72.33
P_{40}	43.96	61.77	44.38	49.08	46.45	49.13	59.30	77.88	62.13	68.64	67.81	67.17
Mean	39.17	43.67	41.76	43.72	44.83		55.62	61.96	59.29	61.66	60.53	
	150 DAP											
P_0	32.91	36.12	42.56	39.32	40.47	38.28						
P_{20}	47.24	45.97	51.93	45.31	47.67	47.39						
P_{30}	60.14	58.47	54.57	70.67	68.28	62.27						
P_{40}	51.71	74.57	53.95	59.28	58.69	59.64						
Mean	48.00	53.78	50.75	53.64	53.78							

	CD at 5%				
	90	105	120	135	150
Phosphorus	0.28	0.21	0.32	0.33	0.31
Phytohormone	0.34	0.24	0.33	0.38	0.36
Interaction	0.62	0.45	0.55	0.70	0.66

Table 107. Effect of soil-applied phosphorus and leaf-applied phytohormones and of their interaction on potassium uptake (mg plant^{-1}) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose P kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
P_0	96	136	139	141	144	131	130	171	190	164	183	168
P_{20}	112	141	136	141	160	138	155	184	182	200	208	186
P_{30}	141	162	161	178	157	161	187	213	226	274	231	226
P_{40}	131	182	153	149	184	158	171	286	205	219	242	225
Mean	120	151	147	155	161		161	214	201	214	216	
	120 DAP						135 DAP					
P_0	274	283	293	268	349	285	352	395	426	418	410	400
P_{20}	264	311	299	303	343	304	399	451	475	411	450	437
P_{30}	332	360	360	400	356	362	465	465	454	544	546	495
P_{40}	317	419	311	353	375	355	456	569	462	500	477	485
Mean	297	343	316	331	356		418	470	454	468	471	
	150 DAP											
P_0	300	366	381	365	344	351						
P_{20}	337	383	402	392	392	385						
P_{30}	402	409	382	460	452	419						
P_{40}	356	495	401	409	440	416						
Mean	349	413	392	402	404							

CD at 5%					
	90	105	120	135	150
Phosphorus	11	16	21	17	15
Phytohormone	13	16	23	19	16
Interaction	25	32	45	36	31

4.6.3.1 Leaf number per plant

Of phosphorus treatments, maximum and minimum values were recorded for P_{30} and the control (P_0) respectively. Treatment P_{30} increased leaf number by 19.24, 23.53, 15.44, 11.03 and 12.03 per cent in comparison with the control at 90, 105, 120, 135 and 150 DAP respectively.

Regarding phytohormones effect, significant maximum and minimum values were given by 10^{-5}M GA_3 and the water-sprayed control (W_0) respectively at all stages. The increase in leaf number due to 10^{-5}M GA_3 over the water-sprayed control was 47.53, 54.17, 31.82, 28.57 and 31.00 per cent at 90, 105, 120, 135 and 150 DAP respectively.

Among interactions, $P_{40}\times10^{-5}$M GA_3 and the control ($P_0\times W_0$) gave significant maximum and minimum values respectively at all samplings. The increase in leaf number due to $P_{40}\times10^{-5}$M GA_3 over the control was 104.18, 135.90, 58.54, 49.50 and 53.80 per cent at 90, 105, 120, 135 and 150 DAP (Table 108).

4.6.3.2 Branch number per plant

Treatment P_{30} at 90 and 105 DAP and P_{40} at 135 and 150 DAP gave significant maximum values. However at 120 DAP, the maximum value for P_{30} was equalled by that for P_{40}. On the other hand, the lowest significant effect was found with the control (P_0) at all stages. Treatment P_{30} gave 19.24, 35.42, 17.01, 19.77 and 20.14 per cent higher value for branch number than the control (P_0) at 90, 105, 120, 135 and 150 DAP respectively.

Regarding phytohormones, the maximum value for branch number per plant was recorded for 10^{-4}M GA_3, and the value differed significantly from those for other treatments at all stages, except 90 DAP, at which it was equalled by that for 10^{-5}M GA_3. Moreover, the value recorded for the water-sprayed control (W_0) was significantly lowest at all samplings. The increase in branch number due to 10^{-4}M GA_3 was 52.18, 41.84, 53.03, 32.29 and 33.74 per cent, and due to 10^{-5}M GA_3 was 47.55, 38.19, 45.72, 24.48 and 25.58 per cent in comparison with water-sprayed control at 90, 105, 120, 135 and 150 DAP respectively.

With regard to interaction effect, $P_{30}\times10^{-4}$M GA_3 at 90 and $P_{40}\times10^{-4}$M GA_3 at 105, 120 and 135 DAP gave significant maximum value. However, the maximum

Table 108. Effect of soil-applied phosphorus and leaf-applied phytohormones and of their interaction on leaf number per plant of *Mentha arvensis* L. at five growth stages.

Fertilizer dose P kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
P_0	39.67	65.00	68.33	61.67	63.33	59.60	78.00	143.33	148.00	135.00	143.00	129.47
P_{20}	44.67	67.67	66.00	63.00	65.00	61.25	110.33	160.33	154.33	150.67	151.67	145.47
P_{30}	59.67	75.00	68.00	77.00	75.67	71.07	121.00	170.67	169.00	174.00	172.00	159.93
P_{40}	51.67	81.00	66.33	73.67	71.00	68.73	117.67	184.00	163.67	162.00	162.33	157.93
Mean	48.92	72.17	67.17	68.84	68.75		106.75	164.58	158.75	155.42	157.17	
	120 DAP						135 DAP					
P_0	205.00	271.00	280.00	232.00	236.33	244.87	362.33	446.33	501.67	430.33	446.67	437.47
P_{20}	211.67	270.33	284.00	237.67	242.00	249.13	372.67	460.67	511.00	433.00	452.00	445.87
P_{30}	240.00	299.33	252.00	308.00	314.00	282.67	404.00	519.33	457.00	524.33	524.00	485.73
P_{40}	227.33	325.00	265.33	290.67	261.67	274.00	391.67	541.67	461.00	484.00	463.00	468.27
Mean	221.00	291.33	270.33	266.92	264.00		382.67	492.00	482.67	467.91	471.42	
	150 DAP											
P_0	342.00	433.33	490.33	417.67	430.00	422.67						
P_{20}	359.33	446.67	507.00	427.33	440.33	436.13						
P_{30}	386.00	508.00	447.00	510.33	516.33	473.53						
P_{40}	373.67	526.00	449.00	470.00	444.00	452.53						
Mean	365.25	478.50	473.33	456.33	457.67							

	CD at 5%				
	90	105	120	135	150
Phosphorus	0.9	1.20	1.47	3.17	2.78
Phytohormone	1.07	1.34	1.64	3.55	3.11
Interaction	2.15	2.69	3.29	7.10	6.22

value for $P_{40}\times10^{-4}$M GA_3 at 120 DAP was equalled by that for $P_{40}\times10^{-5}$M GA_3. Significant minimum value was recorded for the control ($P_0\times W_0$) at all stages, except t 90 DAP, at which its value was equalled by that for $P_{20}\times W_0$. The per cent increase in branch number due to $P_{40}\times10^{-5}$M GA_3 over the control was 94.79, 70.20, 77.47, 80.76 and 84.91 at 90, 105, 120, 135 and 150 DAP respectively (Table 109).

4.6.3.3 Leaf yield per plant

The values given by all soil-applied phosphorus treatments showed significant difference with each other at all stages. Maximum and minimum value was recorded for P_{30} and the control (P_0) respectively. The increase in leaf yield resulted from the application of P_{30} was 17.24, 31.75, 22.95, 20.77 and 18.72 per cent compared with the control at 90, 105, 120, 135 and 150 DAP respectively.

Among phytohormones, significant maximum value was given by 10^{-5}M Kn at 90, 105 and 120 DAP and by 10^{-5}M GA_3 at 135 and 150 DAP. However at 105 DAP, the maximum value given by 10^{-5}M Kn was equal to that for 10^{-5}M GA_3. On the other hand, the value given by the water-sprayed control (W_0) was significantly lowest at all stages. The increase in leaf yield due to 10^{-5}M Kn was 25.51, 16.90, 10.71, 7.34 and 6.80 per cent and due to 10^{-5}M GA_3 was 21.53, 16.37, 8.38 and 7.96 per cent over the water-sprayed control at 90, 105, 120, 135 and 150 DAP respectively.

Regarding interaction effect, $P_{40}\times10^{-5}$M GA_3 gave maximum value at all stages, however, its value was equalled by that for $P_{30}\times10^{-5}$M Kn at 105, 120 and 135 DAP. The control ($P_0\times W_0$) gave significant minimum value at all samplings. Interaction $P_{40}\times10^{-5}$M GA_3 increased leaf yield at 90, 105, 120, 135 and 150 DAP by 100.92, 82.28, 51.85, 39.50 and 39.38 per cent respectively in comparison with the control (Table 110).

4.6.3.4 Stem yield per plant

Treatment P_{30} gave maximum value at all stages, however its effect was at par with that of P_{40} at 90, 120 and 150 DAP. The effect of the control (P_0) was significantly lowest at all samplings. Treatment P_{30} gave 23.10, 34.32, 22.57, 19.79 and 19.58 per cent higher value than the control at 90, 105, 120, 135 and 150 DAP respectively.

Table 109. Effect of soil-applied phosphorus and leaf-applied phytohormones and of their interaction on branch number per plant of *Mentha arvensis* L. at five growth stages.

Fertilizer dose P kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
P_0	6.33	9.67	9.33	8.67	8.33	8.47	15.67	23.66	24.33	18.67	19.67	20.40
P_{20}	6.67	10.33	10.33	9.33	9.67	9.27	17.67	25.33	25.33	18.67	20.33	21.47
P_{30}	8.67	11.00	13.67	12.33	11.67	11.47	20.67	25.67	26.33	19.33	25.67	23.87
P_{40}	7.67	12.33	11.33	10.00	10.00	10.27	19.33	26.67	28.00	19.67	22.67	22.93
Mean	7.34	10.83	11.17	10.08	9.92		18.33	25.33	26.00	19.08	22.08	
	120 DAP						135 DAP					
P_0	26.67	40.33	43.33	32.67	33.67	35.47	36.33	56.33	56.67	48.67	51.67	49.93
P_{20}	28.00	41.00	44.33	36.33	35.67	36.93	48.33	56.33	63.33	54.67	53.33	55.20
P_{30}	33.33	44.33	45.67	40.67	42.33	41.27	54.67	60.67	65.33	60.33	58.00	59.80
P_{40}	30.67	47.33	48.33	37.67	41.00	41.00	52.67	65.67	68.67	59.33	56.33	60.93
Mean	29.68	43.25	45.42	36.84	38.17		48.00	59.75	63.50	55.75	54.83	
	150 DAP											
P_0	35.33	55.33	56.00	47.67	50.67	49.00						
P_{20}	47.33	55.67	62.33	54.00	52.67	54.40						
P_{30}	53.67	59.33	64.67	59.33	57.33	58.87						
P_{40}	51.33	65.33	68.00	58.67	55.33	59.73						
Mean	46.92	58.92	62.75	54.92	54.00							

	CD at 5%				
	90	105	120	135	150
Phosphorus	0.40	0.44	0.48	0.49	0.66
Phytohormone	0.45	0.50	0.53	0.50	0.70
Interaction	0.90	0.98	1.06	1.00	1.87

Table 110. Effect of soil-applied phosphorus and leaf-applied phytohormones and of their interaction on leaf yield (g plant^{-1}) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose P kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
P_0	9.53	11.43	12.20	11.93	12.60	11.54	13.77	16.43	17.83	15.87	16.27	16.03
P_{20}	10.55	11.57	12.10	11.80	12.70	11.74	15.27	16.87	18.80	17.47	18.77	17.44
P_{30}	12.23	14.47	12.43	13.53	15.00	13.53	19.67	19.80	20.40	24.70	21.01	21.12
P_{40}	11.00	15.13	12.60	13.40	14.00	13.21	18.50	25.10	19.10	18.57	22.50	20.75
Mean	10.82	13.15	12.33	12.67	13.58		16.80	19.55	19.03	19.15	19.64	
	120 DAP						135 DAP					
P_0	27.33	30.80	31.33	31.13	33.43	30.80	45.47	48.47	49.23	49.50	49.73	48.84
P_{20}	30.33	34.67	34.27	31.63	34.87	32.95	48.50	54.20	54.57	50.16	52.33	51.95
P_{30}	38.67	34.73	35.60	40.87	39.50	37.87	55.87	55.43	57.90	62.87	60.67	58.55
P_{40}	34.00	41.50	34.03	35.53	36.50	36.13	54.57	63.43	53.60	54.90	56.67	56.63
Mean	32.58	35.27	33.80	35.44	36.07		51.10	55.38	53.82	54.36	54.85	
	150 DAP											
P_0	45.20	48.23	48.93	49.30	49.50	48.32						
P_{20}	48.23	53.23	53.10	49.93	52.13	51.32						
P_{30}	55.70	55.27	53.23	62.73	59.37	57.26						
P_{40}	54.40	63.00	53.03	54.67	56.37	56.29						
Mean	50.88	54.93	52.07	54.16	54.34							

CD at 5%					
	90	105	120	135	150
Phosphorus	0.24	0.15	0.23	0.20	0.18
Phytohormone	0.27	0.17	0.26	0.22	0.20
Interaction	0.54	0.34	0.52	0.44	0.40

With regard to phytohormones, 10^{-5}M Kn at 90, 105 and 120 DAP and 10^{-5}M GA_3 at 135 and 150 DAP gave maximum value. Moreover, the value for 10^{-5}M Kn was equalled by that for 10^{-6}M Kn at 105 DAP and by that for 10^{-5}M GA_3 at 135 and 150 DAP. On the other hand, the value given by the water-sprayed control (W_0) was significantly ~~minimum~~ lower at all samplings. The per cent increase in stem yield due to 10^{-5}M Kn was 32.85, 60.07, 16.82, 14.87 and 14.99 per cent and due to 10^{-5}M GA_3 was 26.46, 55.75, 12.53, 15.09 and 15.28 per cent over the water-sprayed control at 90, 105, 120, 135 and 150 DAP respectively.

Pertaining to interaction effect, $P_{40}\times10^{-5}$M GA_3 gave maximum value at all samplings, however the value was equalled by that for $P_{40}\times10^{-5}$M Kn and $P_{30}\times10^{-6}$M Kn at 90 DAP, and by that for $P_{40}\times10^{-6}$M Kn at 105 DAP. Significant minimum value was registered for the control ($P_0\times W_0$) at all stages. The increase in stem yield due to $P_{40}\times10^{-5}$M GA_3 in comparison with the control was 84.15, 128.98, 49.88, 50.48 and 51.91 per cent at 90, 105, 120, 135 and 150 DAP respectively (Table 111).

4.6.3.5 Herb yield per plant

The value given by P_{30} was significantly ~~maximum~~ higher at all stages, except 120 DAP, at which its value was equalled by that for P_{40}. The significant minimum value was recorded for the control (P_0). The increase in herb yield due to P_{30} in comparison with the control was 18.96, 25.62, 23.00, 20.44 and 19.36 per cent at 90, 105, 120, 135 and 150 DAP respectively.

Among phytohormones, significant maximum value for 10^{-5}M Kn was recorded at 90, 105 and 120 DAP and for 10^{-5}M GA_3 at 135 and 150 DAP. On the other hand, the value given by the water-sprayed control (W_0) was significantly lowest at all stages. The increase in herb yield due to 10^{-5}M Kn was 30.41, 34.68, 13.56, 11.57 and 11.02 per cent, and due to 10^{-5}M GA_3, was 24.97, 32.06, 10.45, 11.66 and 11.55 per cent compared with the water-sprayed control at 90, 105, 120, 135 and 150 DAP respectively.

Regarding interactions, $P_{40}\times10^{-5}$M GA_3 gave significant maximum value at all samplings. The control ($P_0\times W_0$) gave significant minimum value at all stages. Interaction $P_{40}\times10^{-5}$M GA_3 gave 92.77, 101.62, 50.90, 44.81 and 45.41 per cent

Table 111. Effect of soil-applied phosphorus and leaf-applied phytohormones and of their interaction on stem yield (g plant^{-1}) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose P kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
P_0	7.13	9.67	10.37	10.20	10.70	9.61	9.73	15.60	14.97	15.20	15.77	14.25
P_{20}	8.53	10.40	10.30	10.20	11.47	10.18	10.80	15.90	15.07	17.62	18.28	15.53
P_{30}	10.50	11.67	11.77	12.96	12.23	11.83	13.93	19.87	19.42	20.87	21.60	19.14
P_{40}	9.51	13.13	11.30	11.47	13.00	11.68	12.83	22.28	17.63	21.93	20.03	18.94
Mean	8.92	11.28	10.93	11.21	11.85		11.82	18.41	16.77	18.90	18.92	
	120 DAP						135 DAP					
P_0	25.60	26.48	27.35	27.47	31.53	27.69	42.53	49.23	53.73	50.50	51.67	49.53
P_{20}	27.60	27.77	28.53	30.23	31.27	29.18	47.03	51.57	54.90	52.00	53.43	51.79
P_{30}	30.37	34.50	34.47	35.10	35.27	33.94	54.30	61.50	59.50	60.73	60.63	59.33
P_{40}	29.40	38.37	30.83	37.03	33.87	33.90	52.77	64.00	56.47	61.70	60.13	59.01
Mean	28.24	31.78	30.29	32.46	32.99		49.16	56.58	56.15	56.23	56.47	
	150 DAP											
P_0	41.90	48.52	53.50	50.10	51.10	49.16						
P_{20}	46.67	51.27	54.09	51.27	53.27	51.31						
P_{30}	53.90	61.13	58.20	60.53	60.20	58.79						
P_{40}	52.32	63.65	56.02	60.30	59.45	58.35						
Mean	48.70	56.14	55.45	55.55	56.00							

	CD at 5%				
	90	105	120	135	150
Phosphorus	0.20	0.18	0.21	0.11	0.19
Phytohormone	0.22	0.20	0.24	0.13	0.21
Interaction	0.44	0.40	0.47	0.25	0.42

higher value for herb yield than the control at 90, 105, 120, 135 and 150 DAP, respectively (Table 112).

4.6.3.6 Oil content

Treatment P_{30} gave maximum value at all samplings, except 120 DAP, at which its effect was equalled by that for P_{40}. On the other hand, significant minimum value was recorded for the control (P_0) at all stages except 120 DAP, at which it was equalled by that for P_{20}. The per cent increase in oil content due to P_{30} over the control was 12.50, 13.21, 6.25, 8.47 and 8.85 per cent at 90, 105, 120, 135 and 150 DAP, respectively.

Pertaining to phytohormones, the maximum value was recorded for 10^{-5}M GA_3 at all stages, however the value was at par with that of 10^{-5}M Kn, 10^{-6}M Kn and 10^{-4}M Kn at 105 DAP, with that of 10^{-5}M Kn at 135 DAP and with those of 10^{-5}M Kn and 10^{-6}M Kn at 150 DAP. Minimum value was recorded for the water-sprayed control (W_0) at all stages. The increase in oil content due to 10^{-5}M GA_3 was 12.50, 11.32, 16.13, 32.00 and 38.04 per cent, and due to 10^{-5}M Kn, was 8.33, 7.45, 9.68, 30.0 and 36.97 per cent in comparison with the water-sprayed control at 90, 105, 120, 135 and 150 DAP, respectively.

Regarding interactions, $P_{40}\times10^{-5}$M GA_3 gave maximum value at all stages but its effect was equal with that of $P_{30}\times10^{-6}$M Kn and $P_{30}\times10^{-5}$M Kn at 90 and 105 DAP, with that of $P_{30}\times10^{-5}$M GA_3, $P_{30}\times10^{-5}$M Kn and $P_{20}\times10^{-5}$M GA_3 at 120 DAP, with that of $P_{30}\times10^{-5}$M GA_3 and $P_{30}\times10^{-6}$M Kn at 135 DAP and with that of $P_{30}\times10^{-6}$M Kn, $P_{30}\times10^{-5}$M Kn and $P_{30}\times10^{-5}$M GA_3 at 150 DAP. The effect of the control ($P_0\times W_0$) was lowest at all stages. The increase in oil content due to $P_{40}\times10^{-5}$M GA_3 over the control was 34.88, 38.30, 35.71, 61.90 and 78.38 per cent at 90, 105, 120, 135 and 150 DAP, respectively (Table 113).

4.6.3.7 Oil yield per plant

The values recorded for all treatments of phosphorus differed significantly from each other at all samplings. Maximum and minimum value was recorded for P_{30} and the control (P_0), respectively. The per cent increase in oil yield due to P_{30} over the control was 32.31, 48.82, 30.19, 31.82 and 27.97 per cent at 90, 105, 120, 135 and 150 DAP, respectively.

Table 112. Effect of soil-applied phosphorus and leaf-applied phytohormones and of their interaction on herb yield (g plant^{-1}) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose P kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
P_0	16.66	21.10	22.57	22.13	21.15	21.15	23.50	31.41	32.80	31.07	32.04	30.07
P_{20}	18.08	21.97	22.40	22.00	24.17	21.72	26.07	32.77	33.87	35.10	37.05	32.97
P_{30}	22.73	26.14	24.20	26.49	26.23	25.16	33.60	39.67	39.82	45.57	42.61	40.25
P_{40}	20.51	28.26	23.90	24.87	28.03	25.11	31.33	47.38	36.73	40.50	42.53	39.69
Mean	19.50	24.37	23.27	23.87	25.43		28.63	37.81	35.81	38.06	38.56	
	120 DAP						135 DAP					
P_0	52.93	57.28	58.68	58.60	64.96	58.49	88.00	97.70	102.96	100.00	101.40	98.01
P_{20}	57.93	62.44	62.80	60.86	66.14	62.03	95.53	105.77	109.47	102.16	106.56	103.90
P_{30}	69.04	69.23	70.07	76.60	74.77	71.94	110.17	116.91	117.41	123.60	122.13	118.04
P_{40}	63.40	79.87	64.86	72.56	70.40	70.22	107.34	127.43	110.07	110.16	117.36	115.09
Mean	60.83	67.21	64.10	67.16	69.07		100.26	111.95	109.98	111.03	111.86	
	150 DAP											
P_0	87.10	96.75	102.43	99.40	100.62	97.26						
P_{20}	94.90	104.50	107.19	101.43	106.20	102.84						
P_{30}	109.60	116.40	111.60	123.26	119.57	116.09						
P_{40}	106.72	126.65	109.05	114.98	115.82	114.64						
Mean	99.58	111.08	107.68	109.77	110.55							

CD at 5%					
	90	105	120	135	150
Phosphorus	0.32	0.27	0.39	0.44	0.29
Phytohormone	0.35	0.30	0.43	0.46	0.32
Interaction	0.72	0.60	0.85	0.95	0.65

Table 113. Effect of soil-applied phosphorus and leaf-applied phytohormones and of their interaction on oil content (%) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose P kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
P_0	0.43	0.50	0.52	0.46	0.48	0.48	0.47	0.55	0.53	0.55	0.54	0.53
P_{20}	0.47	0.52	0.50	0.51	0.46	0.49	0.52	0.56	0.58	0.54	0.55	0.55
P_{30}	0.50	0.54	0.54	0.56	0.56	0.54	0.58	0.59	0.58	0.62	0.62	0.60
P_{40}	0.53	0.58	0.50	0.47	0.51	0.51	0.55	0.65	0.54	0.54	0.55	0.57
Mean	0.48	0.54	0.51	0.50	0.52		0.53	0.59	0.56	0.56	0.57	
	120 DAP						135 DAP					
P_0	0.56	0.68	0.67	0.63	0.68	0.64	0.84	1.28	1.26	1.24	1.28	1.18
P_{20}	0.63	0.72	0.70	0.60	0.62	0.65	0.91	1.30	1.27	1.28	1.29	1.21
P_{30}	0.65	0.73	0.62	0.69	0.73	0.68	1.12	1.34	1.30	1.34	1.32	1.28
P_{40}	0.63	0.76	0.60	0.66	0.69	0.67	1.06	1.36	1.24	1.30	1.30	1.25
Mean	0.62	0.72	0.65	0.66	0.68		1.00	1.32	1.27	1.29	1.30	
	150 DAP											
P_0	0.74	1.24	1.21	1.23	1.25	1.13						
P_{20}	0.82	1.24	1.26	1.24	1.26	1.16						
P_{30}	1.06	1.28	1.26	1.29	1.29	1.23						
P_{40}	1.01	1.32	1.22	1.23	1.24	1.20						
Mean	0.92	1.27	1.24	1.25	1.26							

CD at 5%					
	90	105	120	135	150
Phosphorus	0.01	0.02	0.02	0.01	0.02
Phytohormone	0.01	0.03	0.02	0.02	0.02
Interaction	0.02	0.05	0.04	0.03	0.04

With regard to phytohormones, 10^{-5}M GA_3 gave significant maximum value for oil yield at all stages, except 90 DAP, at which its value was equalled by that for 10^{-5}M Kn. On the other hand, lowest significant value was recorded for the water-sprayed control (W_0). Treatment of 10^{-5}M GA_3 increased oil yield by 34.86, 29.11, 26.98, 45.79 and 50.61 per cent and due to 10^{-5}M Kn, was 30.67, 23.67, 21.54, 41.81 and 46.60 per cent in comparison with the control at 90, 105, 120, 135 and 150 DAP respectively.

Regarding interactions, $P_{40}\times10^{-5}$M GA_3 and control ($P_0\times W_0$) gave significant maximum and minimum values respectively at all stages. The increase in oil yield due to $P_{40}\times10^{-5}$M GA_3 compared with the control was 113.90, 152.24, 106.14, 137.11 and 148.61 per cent at 90, 105, 120, 135 and 150 DAP respectively (Table 114).

Table 114. Effect of soil-applied phosphorus and leaf-applied phytohormones and of their interaction on oil yield (g plant^{-1}) of *Mentha arvensis* L. at five growth stages.

Fertilizer dose P kg/ha	Growth stages (days after planting)											
	90 DAP						105 DAP					
	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean	W_0	10^{-5}M GA_3	10^{-4}M GA_3	10^{-6}M Kn	10^{-5}M Kn	Mean
P_0	4.10	5.72	6.34	5.49	6.05	5.54	6.47	9.04	9.45	8.73	8.79	8.50
P_{20}	4.96	6.02	6.05	6.02	5.84	5.78	7.94	9.45	10.90	9.44	10.32	9.61
P_{30}	6.12	7.82	6.71	7.58	8.40	7.33	11.41	11.68	11.83	15.31	13.03	12.65
P_{40}	5.83	8.77	6.30	6.30	7.14	6.87	10.18	16.32	10.31	10.03	12.38	11.84
Mean	5.25	7.08	6.35	6.35	6.86		9.00	11.62	10.62	10.88	11.13	
	120 DAP						135 DAP					
P_0	15.30	20.94	20.99	19.61	22.73	19.91	36.38	62.04	62.03	61.38	63.65	57.10
P_{20}	19.11	24.96	23.99	18.98	21.62	21.73	44.14	70.46	69.30	64.20	67.51	63.12
P_{30}	25.14	25.35	22.07	28.20	28.84	25.92	62.57	74.16	75.27	84.25	80.08	75.27
P_{40}	21.42	31.54	20.42	23.45	25.19	24.40	57.84	86.26	66.46	71.37	73.67	71.12
Mean	20.24	25.70	21.87	22.56	24.60		50.23	73.23	68.27	70.31	71.23	
	150 DAP											
P_0	33.45	61.73	59.20	60.64	61.88	55.38						
P_{20}	39.55	66.00	66.91	61.91	65.68	60.01						
P_{30}	59.04	70.75	67.07	80.92	76.59	70.87						
P_{40}	54.94	83.16	64.70	67.24	69.99	68.01						
Mean	46.75	70.41	64.47	67.68	68.54							

CD at 5%					
	90	105	120	135	150
Phosphorus	0.12	0.15	0.15	0.18	0.20
Phytohormone	0.13	0.18	0.15	0.21	0.23
Interaction	0.25	0.35	0.33	0.41	0.45

DISCUSSION

CONTENTS

DISCUSSION

Chapter 5

DISCUSSION

A large proportion of the population of developing countries uses traditional medicine these days for health care, either alone, or in combination with western medication. However, it is well known that the use of herbal drugs remained ignored for a long time by the practioners of modern medicine. Renewed interest in the wide use of herbal medicines by all groups of practioners during the second half of the twentieth century and continuing even today, has increased their demand in the pharmaceutical market manifold. Naturally, this has led to procurement and supply problems. Indiscriminate exploitation of some herbs has led even to their total disappearance. Many others are at the verge of extinction. The alternative to ensure their availability (and quality ~~control~~) is to bring such rare herbs as well as others in great demand under cultivation in hospitable agro-climate and to subject them to improved scientific management practices. No doubt, these are areas to be addressed by researchers interested in the conservation of medicinal herbs with additional aim to recommend to farmers package of agro-practices that are cost-effective. Among medicinal plants, mint (*Mentha arvensis* L.) is considered as one of the most valued essential oil-bearing crop and occupies a considerable area under cultivation in India and abroad. Its constituents, particularly menthol, methyl acetate and menthone are widely used in pharmaceutical formulations and for flavouring many beverages (Misra *et al.*, 2000). The crop requires regular input of N and P for sustained healthy growth. Any approach that could enhance top growth together with better utilization of N and P would be an additional benefit for the cultivation.

Earlier researches ~~have~~ shown that plant hormones particularly GA_3 and Kn are suitable modulators of crop growth (Gupta and Datta, 2001; Khan and Samiullah, 2003, Vyas *et al.*, 2003). This led to postulate that application of GA_3 and Kn could be exploited to help increase foliage growth and possibly ensure higher oil yield of Mentha, since a large proportion of essential oil is extracted from the foliage.

It was, therefore, decided to carryout suitable experiments designed statistically to ~~carryout~~ the following objectives.

1. To study the optimum requirement of soil-applied N and P for the crop.
2. To test the efficacy of sprays of GA_3 and Kn in enhancing the selected parameters of growth and yield influencing positively the physiological activity and improving the quality of the economically important products of the crop.
3. To study the effect of soil applied N or P in combination with foliar spray of GA_3 and Kn on the same lines as in Experiment 1.

5.1 Growth characteristics

Growth is defined as quantitative change, i.e. increase in mass or length. Development, on the other hand, involves both quantitative and qualitative changes, i.e. irreversible change in cells, tissues and organs. The developmental changes, e.g. morphological and metabolic changes, are influenced by intrinsic and extrinsic factors, such as (a) supply and absorption of nutrients, which have critical importance in cell metabolism and (b) involvement of phytohormones, in the regulation of sink-source relationship.

In Experiments 1 and 2, growth characteristics like plant height, leaf area, dry matter, dry weight of stem and leaf, and fresh and dry weights of underground parts of the plant, viz. root along with suckers and root length (Tables 9-13; 21-25) were noted to be favourably affected by N and P application to the soil. The maximal response was observed with N_{90} (Plates 1 and 2) and P_{30} (Plates 3 and 4). The positive effects of N and P may be explained on the basis of the fact that N, in addition to its role in cell division and expansion (Gastal and Lemarie, 2002), functions as a necessary component in several key bio-macromolecules (Salisbury and Ross, 1992; Menghini *et al.*, 1998; Taiz and Zeiger, 1998; Lawlor, 2002). Similarly, P is involved in controlling key enzyme reactions and in the regulation of metabolic pathways (Theodorou and Plaxton, 1993; Schachtman *et al.*, 1998).

The observed advantageous effect of N and P application on the growth characteristics of the plant parts studied are in conformity with earlier workers (Samiullah *et al.*, 1988, 1990; Singh *et al.*, 1991, 1992, 2003; Kothari and Singh, 1995; Rastogi *et al.*, 1997; Chuhan *et al.*, 2000; Rai *et al.*, 2002).

Plate 1: Effect of soil-applied N at 0, 30, 60, 90 and 120 kg/ha on aboveground morphology of *Mentha arvensis* L. at 105 DAP

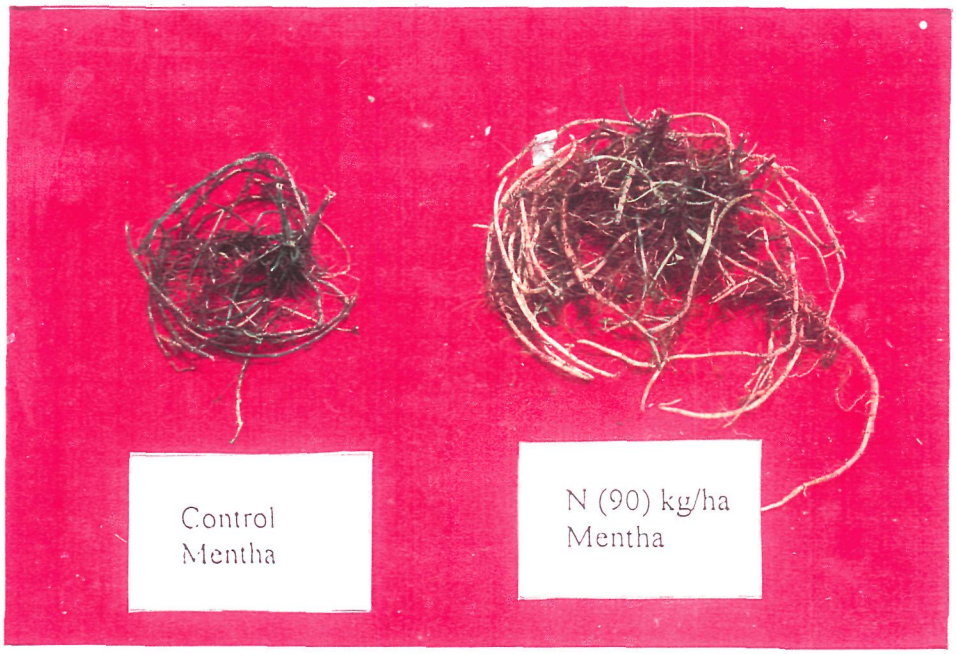

Plate 2: Effect of soil-applied N at 90 kg/ha on underground morphology of *Mentha arvensis* L. at 105 DAP

Plate 3: Effect of soil-applied P at 0, 10, 20, 30 and 40 kg/ha on aboveground morphology of *Mentha arvensis* L. at 105 DAP

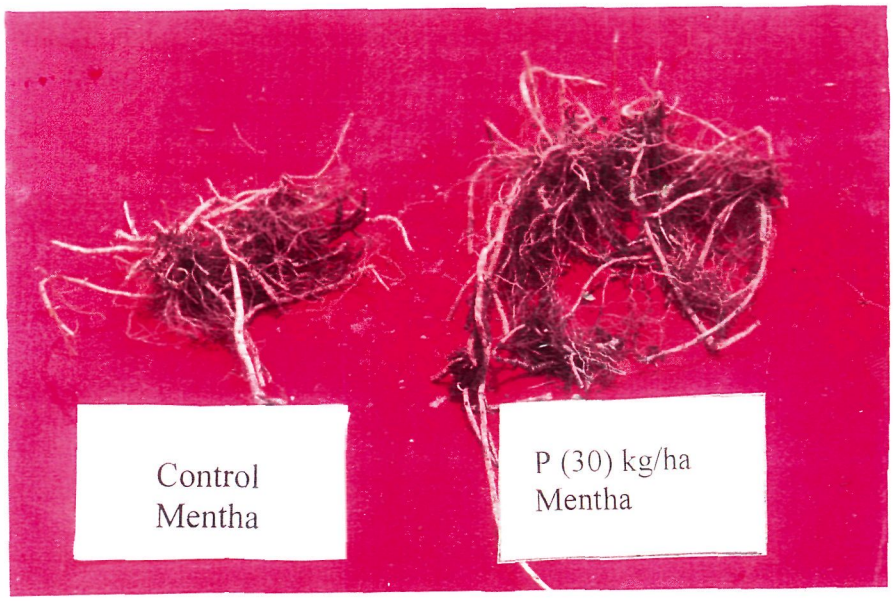

Plate 4: Effect of soil-applied P at 30 kg/ha on underground morphology of *Mentha arvensis* L. at 105 DAP

In Experiments 3 and 4, the favourable effects of the spray of GA_3 and Kn were noted for most of growth characteristics (Tables 33-37; 45-49). The maximum response was obtained with 10^{-4}M GA_3 (Experiment 3; Plates 5 and 6) and 10^{-5}M Kn (Experiment 4; Plates 7 and 8). This may probably be due to the fact that exogenous application of plant growth regulators evoked the intrinsic genetic potential of the crop. The response to the applied concentrations of the particular hormone is due to a change in the subsequent chain of events that may involve other hormones or other factors (Moore, 1989; Taiz and Zeiger, 1998). The favourable effects of GA_3 or Kn have been reported on growth of mentha (El-Keltawi and Crotean, 1987; Sharma *et al.*, 1988; Kewalanand *et al.*, 1998) and of artemisia (Gupta and Datta, 2001).

In Experiment 3, plant height showed striking response to GA_3 (Table 33). In fact, there was linear increase from 10^{-4} to 10^{-2}M GA_3. This was possibly due to the increase in elongation of internodes as a consequence of cell division and cell wall extensibility (Moore, 1989; Taiz and Zeiger, 1998). Furthermore, the hormonal effect (GA_3) was reflected in maximal increase in plant height at 150 DAP (Plate 9). This was because of prolonged vegetative growth due to apical dominance encouraged by GA_3 treatment. A similar observation in an allied species of Mentha (*Mentha spicata*) was observed by Singh *et al.* (1999).

In Experiments 5 and 6, the plants showed more response to the interactions N×GA_3/Kn and P×GA_3/Kn in comparison with those of their individual effect with regard to the growth characteristics (Tables 57-67; 86-96). The highest response for most of the characteristics was obtained with N_{90}×10^{-5}M GA_3 (Experiment 5; Plates 10 and 11) and with P_{40}×10^{-5}M GA_3 (Experiment 6; Plates 12 and 13). This was due to the synergetic interplay of the applied nutrients and phytohormones within the optimum ~~levels~~ ranges. Under normal circumstances, a balanced nutrient profile helps in maintaining maximum growth traits. When such maximal growth occurs, the requirement for increased nutrient concentration signals a hormonal imbalance which may be compensated only by the supply of phytohormones, particularly GA_3 and cytokinins either directly or through increased mineral nutrition (Amzallag *et al.*, 1992). Similar positive effect of the interaction of mineral nutrients and growth regulators on the growth of various other crops has been reported by other workers

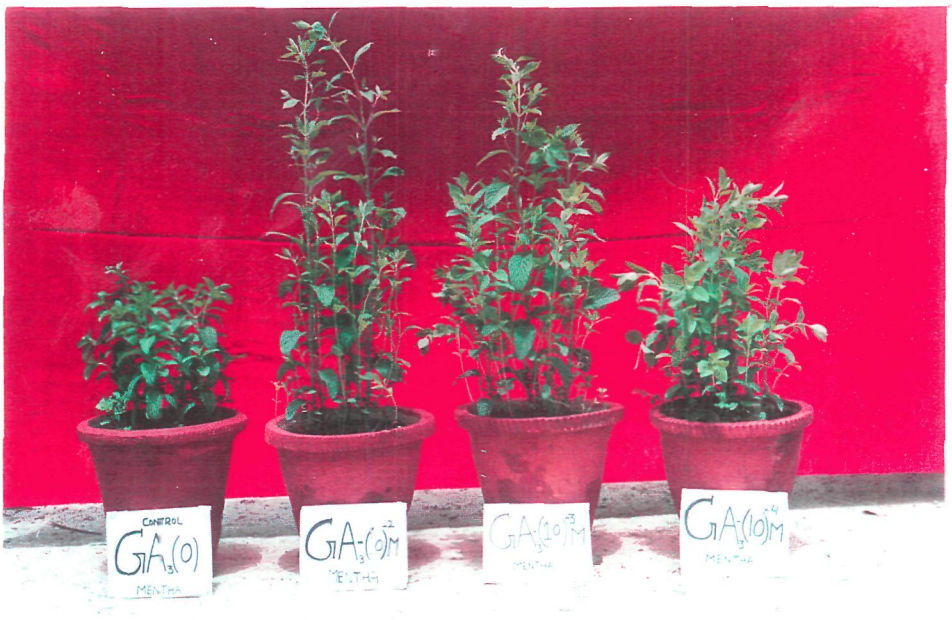

Plate 5: Effect of leaf-applied GA_3 at 0, 10^{-4}, 10^{-3} and 10^{-2}M on aboveground morphology of *Mentha arvensis* L. at 105 DAP

Plate 6: Effect of leaf-applied GA_3 at 10^{-4}M on underground morphology of *Mentha arvensis* L. at 105 DAP

Plate 7: Effect of leaf-applied Kn at 0, 10^{-6}, 10^{-5} and 10^{-4}M on aboveground morphology of *Mentha arvensis* L. at 105 DAP

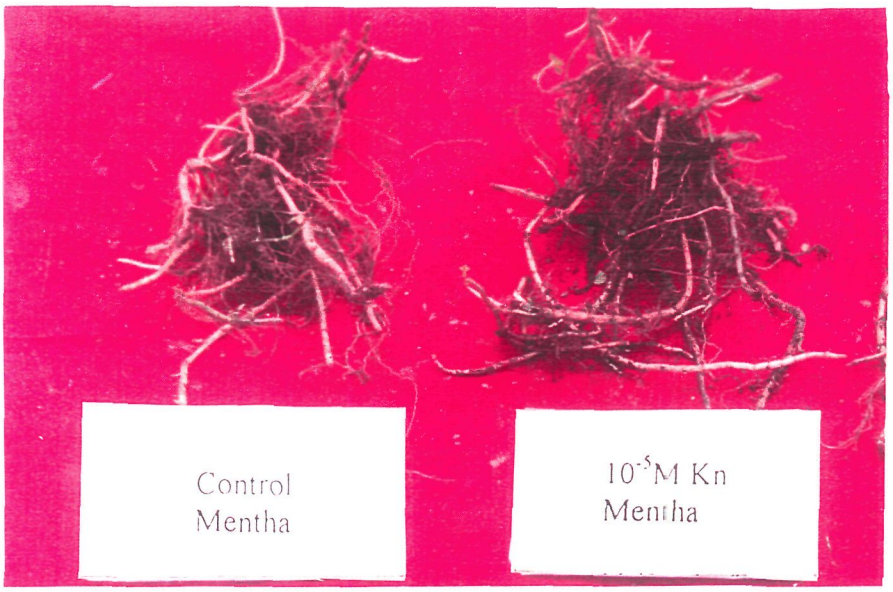

Plate 8: Effect of leaf-applied Kn at 10^{-5}M on underground morphology of *Mentha arvensis* L. at 105 DAP

Plate 9: Effect of leaf-applied GA_3 at 0, 10^{-4}, 10^{-3}, 10^{-2} M on plant height of *Mentha arvensis* L. at 150 DAP

Plate 10: Combined effect of soil-applied N at 90 kg/ha and leaf-applied GA_3 at 10^{-5}M on aboveground morphology of *Mentha arvensis* L. at 105 DAP

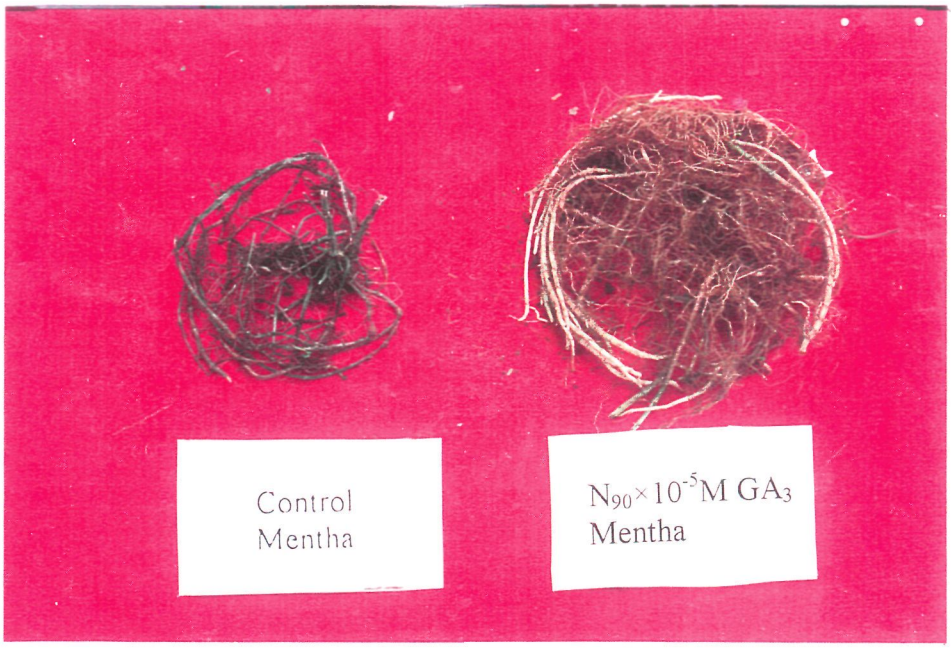

Plate 11: Combined effect of soil-applied N at 90 kg/ha and leaf-applied GA_3 at 10^{-5}M on underground morphology of *Mentha arvensis* L. at 105 DAP

Plate 12: Combined effect of soil-applied P at 40 kg/ha and leaf-applied GA_3 at 10^{-5}M on aboveground morphology of *Mentha arvensis* L. at 105 DAP

Plate 13: Combined effect of soil-applied P at 40 kg/ha and leaf-applied GA_3 at 10^{-5}M on underground morphology of *Mentha arvensis* L. at 105 DAP

(Grewal and Kolar, 1990; Prasad and Shukla, 1991; Shinde *et al.*, 1991; Nylor and Stephen, 1993; Kalita *et al.*, 1995). The results of Experiments 1-6 reveal that almost all growth characteristics studied showed maximum increase at 105 days after planting (DAP) which declined at later stages. This might be because of the fact that the absorption capacity of underground part of the plant decreases as plant ages. This factor might have created discernible constraint at later growth stages of crop, where the competition for nutrients and other inputs was probably more intense. Although the morphology of underground part is genetically controlled (Mengel and Kirkby, 1996), it is also influenced by the characteristics of soil and soil nutrient status.

Data of Experiments 5 and 6 reveal that the applied nutrients, in combination with GA_3 could not improve the underground parts (suckers and roots) of the plant to the extent exhibited by Kn combinations. The maximum response for underground parts was obtained with $N_{90}\times10^{-6}$M Kn (Experiment 5; Plate14) and $P_{30}\times10^{-6}$M Kn (Experiment 6; Plate15). The reason for this may be that GA_3 (probably as a consequence of its marked influence on stem elongation) accelerated mobilization of photosynthetates from leaves to stem on priority basis. This might have limited the carbohydrate supply to the subterranean plant parts. However, stimulation of shoot growth due to GA_3 was further accelerated by the application of nutrients.

5.2 Physiological characteristics

The biomass accumulation in crop relies on interregulation of multiple physiological processes. To regulate these processes efficiently, crop needs adequate supply of resources. Sufficient supply of nutrients stimulates leaf growth and photosynthesis (Lawlor, 2002). It is well known fact that prolific amount of growth can be achieved by maximizing photosynthesis (Baruch and Goldstein, 1999; Durand and Goldstein, 2001; McDowell, 2002). However, higher photosynthetic rates can be achieved by maximizing biochemical capacity (McDowell, 2002). Moreover, large amount of chlorophyll per unit area needed to capture energy efficiently used in photosynthesis (Lawlor, 2002). Therefore, it is thought appropriate to ~~made~~ emphasis on some photosynthetic characteristics for present experiments (1-6).

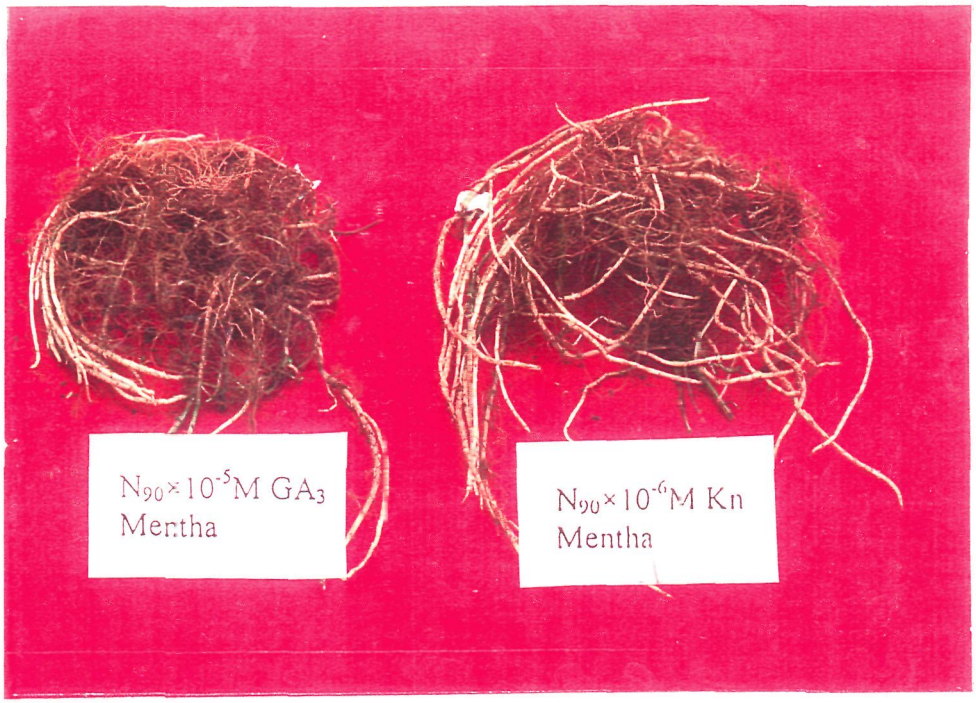

Plate 14: Comparison of the effect of $N_{90}\times10^{-6}$M Kn and $N_{90}\times10^{-5}$M GA_3 on underground morphology of *Mentha arvensis* L. at 105 DAP

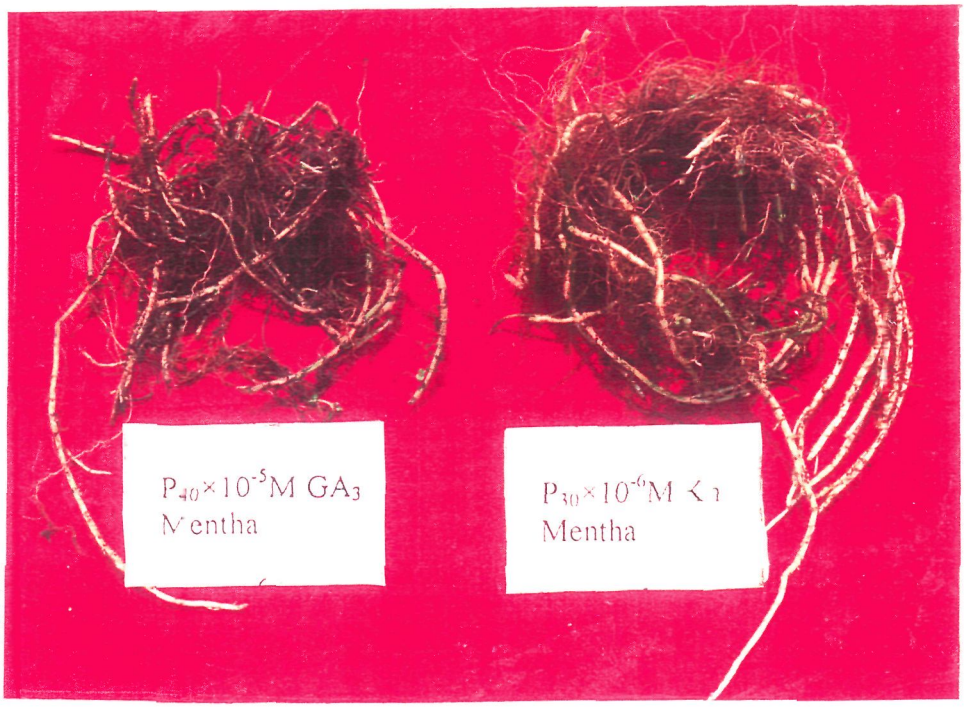

Plate 15: Comparison of the effect of $P_{30}\times10^{-6}$M Kn and $P_{40}\times10^{-5}$M GA_3 on underground morphology of *Mentha arvensis* L. at 105 DAP

5.2.1 Photosynthetic characteristics

Plants constantly seek nutrients in their environment and modulate their metabolic activities as well as development so as to adapt efficiently to the nutritional status. The role of nitrogen is intimately related with photosynthesis (Lawlor, 2002). Similarly, inorganic phosphate (P_i) incorporated in the end products of photosynthesis needs to be recycled to the reactions of photosynthesis, in particular, phosphorylation which is very sensitive to P_i concentrations (Quick and Mills, 1988) in order to sustain photosynthesis (Paul and Foyer, 2001). Also, a positive correlation has been reported between N and chlorophyll content (Evans and Therashima, 1988; Menghini *et al.*, 1998). In addition to that increase in chlorophyll content is known to be responsible for an increase in the photosynthetic rate. Further, it has been reported that N-fertilization has a direct effect on thylakoids and grana formation (Menghini *et al.*, 1998). Manipulation of P_i supply to chloroplast directly or to P_i-sequestering compounds has shown that photosynthesis is inhibited if the P_i concentration of the chloroplast were either low or too high (Cockburn *et al.*, 1967; Herold, 1980). The results of Experiments 1 and 2 (Tables 14-15; 26-27) reveal that applied nutrients (N and P) resulted in significantly advantageous response for all characteristics related to photosynthesis such as photosynthetic rate, stomatal conductance, photosynthetic water-use efficiency, chlorophyll content and chlorophyll harvest. The optimum response shown by these characteristics was found for N_{90} (Experiment 1) and P_{30} (Experiment 2). Moreover, foliar sprays of GA_3 (Experiment 3) and Kn (Experiment 4) also affected positively to these attributes studied (Tables 38-39; 50-51). Maximal response was obtained in the treatment containing 10^{-4}M GA_3 (Experiment 3) and 10^{-5}M Kn (Experiment 4).

The increase in photosynthetic rate due to GA_3 may be due to an increase in cyclic and non-cyclic phosphorylation (Naindu and Swamy, 1995). The role of Kn might be attributed to the involvement of cytokinins in general as they stimulate the synthesis of RUBISCO, small subunits (Lerbs *et al.*, 1984; Ohya and Suzuki, 1991) and photosystem I (Toyama *et al.*, 1996) as also Kn stimulates the development of sun-type chloroplasts (Lichtenthaler and Burkart, 1999), a coordination among these factors, therefore cordially might have increased photosynthesis. Moreover,

favourable effects of phytohormones particularly GA_3 or Kn have also been reported on photosynthesis and stomatal conductance (Naindu and Swamy, 1995; Pandey *et al.*, 2001), photosynthetic water use efficiency (Pandey *et al.*, 2001) and chlorophyll content (Singh and Hippalgaonkar, 1993; Naindu and Swamy, 1995; Singh and Misra, 2001).

Let us now consider the last two experiments which were performed to record the interaction effect between soil applied nutrients and leaf-applied phytohormones. In Experiment 5, the maximum value was given by $N_{90}\times10^{-5}$M GA_3 (Tables 68-72), and in Experiment 6, by $P_{40}\times10^{-5}$M GA_3 (Tables 97-101) for most of photosynthetic characteristics studied. The recorded data of Experiments 5 & 6 reveal that the photosynthetic rate increased with increase in stomatal conductance that could be attributed to enhanced photosynthetic water-use efficiency (Tables 15, 27, 39, 51, 70-72, 99-101).

The statement may be more appropriately made to emphasize the other way relationship. It may be argued with equal importance that the increase in photosynthesis might be responsible for increase in stomatal conductance as both are interdependent (Wong *et al.*, 1979; Faville *et al.*, 1999). Similarly, these photosynthetic traits cumulatively improved the photosynthetic water-use efficiency (Das *et al.*, 1999) leading to the production of additional photoassimilates. The increase in all these photosynthetic activities may be attributed to the positive effect of sufficiency level of applied nutrients and phytohormones as well as the synergetic interplay of these two factors within optimum limits. This finding gets support from strong positive correlations (Tables 135-139; 140-144). It may be safely concluded that the increase in stomatal conductance, chlorophyll content and net photosynthetic rate resulted in improved performance of the crop. Such an effect has also been reported on various crops by Field (1983), DeJong and Doyle (1985), Evan and Terashima (1988), Huber *et al.* (1989), Liu and Dickman (1992) and Khan *et al.* (2000).

In the present study one more attribute (chlorophyll harvest) was noted to be positively linked to the interprogrammed association of stomatal conductance, chlorophyll content, photosynthetic rate with concomitant increase in photosynthetic

water-use efficiency (Tables 14-15; 26-27; 38-39; 50-54; 68-72; 97-101). This could also account for the observed improvement in the performance of crop.

The observed changes and interrelationship of these characteristics which were caused due to application of N or P, GA_3 and Kn separately or in combination is being reported here for first time in Mentha.

5.2.2 Nutrient contents

The nutrient status of a crop is one of the most important attribute employed to assess the uptake of nutrients and their availability in the soil (Jeschke *et al.*, 1992; Nkoa *et al.*, 2001; Gastal and Lemarie, 2002; Jeuffroy *et al.*, 2002). Moreover, when added to soil in accordance with need of the crop, nutrients present in the applied fertilizers improve the quality and quantity of the crop. These, in fact, are criteria used to assess the efficiency of the fertilizers used for the crop. In Experiments 1 and 2, the N and P concentration in plants enhanced linearly with the applied doses of N and P upto N_{90} and P_{30}, respectively (Tables 16, 28). That the supply of nutrients enhanced their concentration in the plants is also in accordance with the findings of previous workers (Corntortill and Steele, 1981; Pandrangi *et al.*, 1990; Helapyati and Sheelavantar, 1992; Naik *et al.*, 1993; Kalita *et al.*, 1995; Belanger and Richards, 1999; Madakadze *et al.*, 1999; Nehra *et al.*, 2001).

5.2.3 Nutrient uptake

The pattern of nutrient uptake of a crop is a highly variable criterion during its development and is largely influenced by the extent of supply and demand of the crop. Naturally crop metabolism plays the most important role here (Schachtman *et al.*, 1998; Gastal and Lemarie, 2002).

In the present set of experiments (1-6), the uptake of NPK was favourably affected by the supply of N and P in Experiments 1 and 2 (Tables 17, 29), by foliar spray of GA_3 and Kn in Experiments 3 and 4 (Tables 41, 53) and by the combination of the applied nutrients and phytohormones in Experiments 5 and 6 (Tables 76-78; 105-107). Maximum uptake was noted in treatments N_{90} (Experiment 1), P_{30} (Experiment 2), 10^{-4}M GA_3 (Experiment 3), 10^{-5}M Kn (Experiment 4), $N_{90}\times10^{-5}$M GA_3 (Experiment 5) and $P_{40}\times10^{-5}$M GA_3 (Experiment 6). Therefore, it can be envisaged that the uptake pattern of NPK might have resulted from their involvement

in the metabolism of the plant in general that would modulate its photosynthetic machinery, and through it, dry matter accumulation. This finding gets support from the positive correlation noted between dry matter and uptake of NPK (Tables 115-144). In all the experiments (1-6), the period of maximum increase in NPK uptake coincided with the period of maximum increase in dry matter accumulation, i.e. 105 DAP of crop growth. This implies that the treated plants were able to receive adequate amount of nutrients at the right time in accordance with their requirement, which might have contributed to the maximum accumulation of reserve food in plants.

In Experiment 1, the maximum increase in N uptake was reflected at 150 DAP. A plausible explanation for this observation may be that N was presumably stored and, therefore, rendered metabolically inactive in the form of proteins (Pate *et al.*, 1979; Heilmeier and Monson, 1994; Lawlor, 2002) at the early stage of crop growth. The stored proteins might have got hydrolysed and translocated subsequently via phloem at later stages of crop development.

The results of Experiments 3 and 4 reveal that the uptake pattern of K was more pronounced than that of N and P. This implies that, as far as uptake is concerned, K is a strong competitor with the other cation species (Mengel and Kirkby, 1996), the extreme mobility of K throughout entire plant may be facilitated by the unhindered permeability of membranes to it (Salisbury and Ross, 1992). Increase in nutrient uptake in plants other than mentha due to nutrient supply has been reported earlier (Kamprath, 1987; Ercoli *et al.*, 1996; Schachtman *et al.*, 1998; Gastal and Lemarie, 2002; Lawlor, 2002; Nehra *et al.*, 2001). Moreover, favourable effect of phytohormones on nutrient uptake has been observed by earlier workers (Guardia and Benlloch, 1980; Simpson *et al.*, 1982; Dhakal and Erdei, 1986; Nylor and Stephen, 1993).

In the present study (Experiments 1-6), it has also been observed that the per cent increase for most of physiological characteristics studied showed a decreasing trend after 105 DAP growth stage. This was possibly due to the decreasing density of photosynthetic pigments (chlorophylls) and enzymes per unit leaf area as the plant advances in age (Hesketh *et al.*, 1981; Bhagsari and Brown, 1986; Davies *et al.*, 1987).

5.3 Yield characteristics

Yield is the manifestation of several complex morphological and physiological attributes of the crop. In some vegetable crops and forage, the vegetative parts of the crop are important for economic yield. This applies amply to *Mentha arvensis* L. In the experiments under discussion (Experiments 1-6), leaf fresh weight, stem fresh weight, leaf number and branch number were selected as yield parameters in addition to herb and oil yield. The results (Tables 18-20; 30-32; 42-44; 54-56; 79-85; 108-114) revealed that increased shoot length provide better opportunities for enhanced leaf production, branch number, leaf yield and stem yield which positively contributed towards herb yield. The most suitable treatments (N_{90} in Experiment 1 and P_{30} in Experiment 2, 10^{-4}M GA_3 in Experiment 3, 10^{-5}M Kn in Experiment 4, $N_{90}\times10^{-5}$M GA_3 in Experiment 5 and $P_{40}\times10^{-5}$M GA_3 in Experiment 6) showed maximal positive response with regard to most yield characteristics. The enhancement was due to developmental changes, which might have been internally better programmed as a result of the treatments. These include modulation of photosynthesis and source-sink relationships as also partitioning and distribution of assimilates within limits which were finally manifested in yield attributes and oil yield.

Since leaves constitute main part in oil biogenesis and accumulation in mentha (Farooqi *et al.*, 1999), ~~Therefore,~~ enhanced leaf number area and mass would be expected to contribute ~~efficiently more to~~ to greater oil production. This is actually the case in present study. This observation ~~gets support from~~ is supported by the strong positive correlation between leaf parameters and oil yield (Tables 115-144).

The favourable effect of N and P on oil yield of mentha species has been reported by Patra *et al.* (1998), Ali *et al.* (1999), Chuhan *et al.* (2000), Kothari and Singh (2000). Moreover, involvement of phytohormones in enhancing essential oil yield of various crops has also been reported by earlier workers (Eid and Ahmad, 1976; El-Keltawi and Crouteau, 1986, 1987; Sharma *et al.*, 1988; Singh and Hippalgaonkar, 1993; Bhaskar *et al.*, 1997).

The accelerated interaction effect of mineral nutrients and phytohormones ($N\times GA_3$/Kn or $P\times GA_3$/Kn) on essential oil content and yield in comparison to their individual effect might be due to synergetic impact of both inputs. It is noteworthy

that this aspect of the research in the field of plant physiology has not been reported earlier.

The essential oil biosynthesis is an integration of several metabolic pathways which require association of several metabolic steps including continuous production of precursors as also their transport and translocation to the active site of synthesis. Any disruption in normal metabolic pathways affects the sequence of steps in oil biosynthesis. Thus a plant may adjust its metabolic pathway in response to various factors, including nutrient and phytohormone application (Singh *et al.*, 1999).

In present study, the oil content has been noted to be ~~ameliorated~~ enhanced by the application of N and P. The maximum response was obtained with N_{90} in Experiment 1 (Table 20) and P_{30} in Experiment 2 (Table 32). The oil content of the crop being positively influenced by the supply of nutrients is in agreement with the finding of earlier workers (Sudhendra *et al.*, 1993; Rastogi *et al.*, 1997; Ali *et al.*, 1999; Rao and Shaktwal, 2001).

In Experiments 3 and 4, foliar spray of GA_3 and Kn also favourably affected the oil content of the crop. Maximum oil content was obtained with 10^{-4}M GA_3 in Experiment 3 (Table 44) and 10^{-5}M Kn in Experiment 4 (Table 56). The positive influence of phytohormones on essential oil accumulation has also been reported by other research workers (El-Keltawi and Croteau, 1986, 1987; Umesha *et al.*, 1991; Vasundhara *et al.*, 1992; Singh and Hippalgaonkar, 1993; Bhaskar *et al.*, 1997; Kewalanad *et al.*, 1998). Data of Experiments 5 and 6 reveal that application of N and P in combination with foliar sprays of GA_3 or Kn had profound effect on oil accumulation. Maximum value was recorded for $N_{90}\times10^{-5}$M GA_3 in Experiment 5 (Table 84) and $P_{40}\times10^{-5}$M GA_3 in Experiment 6 (Table 113).

The increase in oil accumulation might be due to increase in photosynthesis because production of photosynthetates and factors affecting photosynthesis are important determinants of oil and its composition (Srivastava and Sharma, 1991). Moreover, photosynthetic characteristics, among other factors, are at the centre stage in making carbon shareable and separable for anabolism of oil components (Sangwan *et al.*, 2001).

5.4 Conclusions

Keeping all results in view, the performance of Mentha crop particularly (*Mentha arvensis* L.) was studied for the first time under agro-climates of Aligarh, Western Uttar Pradesh and it was found that:-

1. The crop flourishes well, the most appropriate stage for crop harvesting was found at 105 days after planting (DAP).
2. The crop responded well to individual application of soil-applied N at 90kg/ha and P at 30kg/ha.
3. Individual effect of leaf-applied GA_3 and Kn, each at 10^{-5}M proved best for most characters studied.
4. Combined application of soil-applied 90kg N/ha and leaf-applied GA_3 at 10^{-5}M proved more effective particularly for above the ground parts than their individual application.
5. The better performance of the crop particularly aboveground morphology was observed when crop was grown with soil-applied P at 40 kg/ha supplemented with leaf-applied GA_3 at 10^{-5}M.
6. Combination of soil-applied 90 kg N/ha and leaf-applied 10^{-6}M Kn proved best for underground parts of the crop.
7. The underground morphology of the crop was also more favourably affected by the application of soil-applied 30kg P/ha supplemented with leaf-applied 10^{-6}M Kn.

5.5 Future Prospects

The aspects lie in future research is to study and understand the following problems.

1. To study the combined effect of leaf-applied nutrients and phytohormones on commercially field grown crop.
2. The endogenous concentrations of phytohormones particularly, GA_3 and kinetin will be studied.
3. Development morphology of essential oil secretory glands which are genetically fixed in leaves will be envisaged.
4. Enzymes involved in essential oil synthesis will be assayed.

Table 115. Correlation co-efficient (r) values among different parameters and with oil yield in *Mentha arvensis* L. at 90 DAP (Exp. 1)

Parameters	Plant Height	Leaf yield	Leaf number	Leaf area	Herb yield	ADW	N Uptake	P Uptake	K Uptake	Chl	P_N	PWUE	Oil Content
Leaf yield	0.778												
Leaf number	0.983**	0.878*											
Leaf area	0.991**	0.807	0.989**										
Herb yield	0.893*	0.976**	0.960**	0.913*									
ADW	0.887*	0.970**	0.955*	0.906*	0.997**								
N Uptake	0.945*	0.936*	0.989**	0.963**	0.988**	0.980**							
P Uptake	0.885*	0.967**	0.956*	0.919*	0.992**	0.984**	0.987**						
K Uptake	0.835	0.989**	0.922*	0.872	0.989**	0.980**	0.969**	0.993**					
Chl	0.733	0.956*	0.837	0.763	0.941*	0.959**	0.885*	0.923*	0.938*				
P_N	0.868	0.916*	0.936*	0.915*	0.958*	0.961**	0.958*	0.978**	0.957*	0.919*			
PWUE	0.863	0.901*	0.929*	0.905*	0.948*	0.959**	0.944*	0.962**	0.938*	0.931*	0.995**		
Oil Content	0.885*	0.935*	0.949*	0.914*	0.976**	0.986**	0.966**	0.975**	0.959**	0.954*	0.987**	0.991**	
Oil Yield	*0.784*	*0.996***	*0.884**	*0.822*	*0.975***	*0.966***	*0.943**	*0.978***	*0.996***	*0.943**	*0.934**	*0.914**	*0.938**

* ($p = 0.05$) = 0.878
** ($p = 0.01$) = 0.959

ADW = Aboveground dry weight
Chl = Chlorophyll content
P_N = Photosynthetic rate
PWUE = Photosynthetic water use efficiency

Table 116. Correlation co-efficient (r) values among different parameters and with oil yield in *Mentha arvensis* L. at 105 DAP (Exp. 1)

Parameters	Plant Height	Leaf yield	Leaf number	Leaf area	Herb yield	ADW	N Uptake	P Uptake	K Uptake	Chl	P_N	PWUE	Oil Content
Leaf yield	0.850												
Leaf number	0.880*	0.967**											
Leaf area	0.847	0.998**	0.977**										
Herb yield	0.818	0.997**	0.961**	0.998**									
ADW	0.862	0.998**	0.975**	0.999**	0.997**								
N Uptake	0.871	0.994**	0.968**	0.996**	0.993**	0.998**							
P Uptake	0.772	0.985**	0.957*	0.991**	0.995**	0.987**	0.982**						
K Uptake	0.749	0.969**	0.903*	0.969**	0.983**	0.969**	0.974**	0.983**					
Chl	0.854	0.988**	0.930*	0.982**	0.986**	0.987**	0.991**	0.968**	0.980**				
P_N	0.850	0.999**	0.964**	0.996**	0.995**	0.996**	0.990**	0.981**	0.964**	0.987**			
PWUE	0.843	0.999**	0.968**	0.998**	0.997**	0.997**	0.991**	0.985**	0.966**	0.985**	0.999**		
Oil Content	0.863	0.902*	0.802	0.876	0.880*	0.890*	0.897*	0.830	0.870	0.940*	0.907*	0.895*	
Oil Yield	0.902*	0.993**	0.983**	0.993**	0.984**	0.995**	0.993**	0.968**	0.943*	0.979**	0.992**	0.992**	0.898*

* $(p = 0.05) = 0.878$
** $(p = 0.01) = 0.959$

ADW = Aboveground dry weight
Chl = Chlorophyll content
P_N = Photosynthetic rate
PWUE = Photosynthetic water use efficiency

Same editorial comments as Table 115
for Tables 116–144, Consistency
of lower case + upper case in
labels

Table 117. Correlation co-efficient (r) values among different parameters and with oil yield in *Mentha arvensis* L. at 120 DAP (Exp. 1)

Parameters	Plant Height	Leaf yield	Leaf number	Leaf area	Herb yield	ADW	N Uptake	P Uptake	K Uptake	Chl	P_N	PWUE	Oil Content
Leaf yield	0.967**												
Leaf number	0.974**	0.974**											
Leaf area	0.969**	0.998**	0.981**										
Herb yield	0.975**	0.997**	0.987**	0.997**									
ADW	0.976**	0.995**	0.971**	0.997**	0.992**								
N Uptake	0.971**	0.977**	0.941*	0.980**	0.970**	0.992**							
P Uptake	0.969**	0.998**	0.985**	0.997**	0.999**	0.990**	0.966**						
K Uptake	0.996**	0.976**	0.977**	0.982**	0.981**	0.989**	0.985**	0.976**					
Chl	0.975**	0.987**	0.950*	0.987**	0.980**	0.996**	0.998**	0.978**	0.986**				
P_N	0.982**	0.974**	0.942*	0.974**	0.969**	0.989**	0.997**	0.964**	0.989**	0.997**			
PWUE	0.959**	0.957*	0.911*	0.960**	0.947*	0.979**	0.996**	0.942*	0.973**	0.991**	0.994**		
Oil Content	0.925*	0.972**	0.967**	0.965**	0.979**	0.946*	0.903*	0.982**	0.925*	0.925*	0.903*	0.866	
Oil Yield	0.962**	0.995**	0.983**	0.991**	0.998**	0.982**	0.953*	0.999**	0.967**	0.968**	0.953*	0.926*	0.990**

* $(p = 0.05) = 0.878$
** $(p = 0.01) = 0.959$

ADW = Aboveground dry weight
Chl = Chlorophyll content
P_N = Photosynthetic rate
PWUE = Photosynthetic water use efficiency

Table 118. Correlation co-efficient (r) values among different parameters and with oil yield in *Mentha arvensis* L. at 135 DAP (Exp. 1)

Parameters	Plant Height	Leaf yield	Leaf number	Leaf area	Herb yield	ADW	N Uptake	P Uptake	K Uptake	Chl	P_N	PWUE	Oil Content
Leaf yield	0.993**												
Leaf number	0.996**	0.985**											
Leaf area	0.994**	0.997**	0.992**										
Herb yield	0.993**	0.993**	0.984**	0.989**									
ADW	0.992**	0.993**	0.984**	0.988**	0.999**								
N Uptake	0.994**	0.993**	0.995**	0.998**	0.992**	0.992**							
P Uptake	0.996**	0.985**	0.999**	0.993**	0.982**	0.982**	0.995**						
K Uptake	0.976**	0.982**	0.956*	0.970**	0.971**	0.971**	0.958*	0.956*					
Chl	0.993**	0.997**	0.988**	0.996**	0.997**	0.997**	0.997**	0.987**	0.969**				
P_N	0.997**	0.989**	0.999**	0.994**	0.989**	0.988**	0.998**	0.999**	0.957*	0.992**			
PWUE	0.985**	0.979**	0.994**	0.991**	0.975**	0.975**	0.995**	0.995**	0.932*	0.985**	0.995**		
Oil Content	0.975**	0.972**	0.974**	0.977**	0.947*	0.947*	0.965**	0.977**	0.969**	0.958*	0.969**	0.962**	
Oil Yield	0.990**	0.997**	0.977**	0.989**	0.988**	0.989**	0.982**	0.976**	0.994**	0.989**	0.979**	0.963**	0.974**

* $(p = 0.05) = 0.878$
** $(p = 0.01) = 0.959$

ADW = Aboveground dry weight
Chl = Chlorophyll content
P_N = Photosynthetic rate
PWUE = Photosynthetic water use efficiency

Table 119. Correlation co-efficient (r) values among different parameters and with oil yield in *Mentha arvensis* L. at 150 DAP (Exp. 1)

Parameters	Plant Height	Leaf yield	Leaf number	Leaf area	Herb yield	ADW	N Uptake	P Uptake	K Uptake	Chl	P_N	PWUE	Oil Content
Leaf yield	0.987**												
Leaf number	0.986**	0.990**											
Leaf area	0.993**	0.995**	0.998**										
Herb yield	0.983**	0.997**	0.989**	0.993**									
ADW	0.983**	0.997**	0.989**	0.993**	0.999**								
N Uptake	0.992**	0.995**	0.989**	0.994**	0.997**	0.997**							
P Uptake	0.941*	0.923*	0.941*	0.941*	0.944*	0.944*	0.954*						
K Uptake	0.973**	0.971**	0.968**	0.973**	0.984**	0.984**	0.989**	0.983**					
Chl	0.978**	0.987**	0.999**	0.995**	0.986**	0.986**	0.983**	0.935*	0.961**				
P_N	0.987**	0.986**	0.999**	0.997**	0.986**	0.986**	0.989**	0.953*	0.972**	0.997**			
PWUE	0.971**	0.973**	0.994**	0.988**	0.978**	0.978**	0.978**	0.958*	0.967**	0.996**	0.996**		
Oil Content	0.985**	0.978**	0.989**	0.990**	0.967**	0.966**	0.971**	0.900*	0.934*	0.986**	0.987**	0.974**	
Oil Yield	0.992**	0.995**	0.984**	0.992**	0.986**	0.985**	0.988**	0.903*	0.955*	0.978**	0.980**	0.961**	0.987**

* ($p = 0.05$) = 0.878
** ($p = 0.01$) = 0.959

ADW = Aboveground dry weight
Chl = Chlorophyll content
P_N = Photosynthetic rate
PWUE = Photosynthetic water use efficiency

Table 120. Correlation co-efficient (r) values among different parameters and with oil yield in *Mentha arvensis* L. at 90 DAP (Exp. 2)

Parameters	Plant Height	Leaf yield	Leaf number	Leaf area	Herb yield	ADW	N Uptake	P Uptake	K Uptake	Chl	P_N	PWUE	Oil Content
Leaf yield	0.930*												
Leaf number	0.993**	0.962**											
Leaf area	0.995**	0.948*	0.996**										
Herb yield	0.994**	0.896*	0.978**	0.989**									
ADW	0.799	0.656	0.766	0.739	0.777								
N Uptake	0.981**	0.868	0.967**	0.980**	0.992**	0.741							
P Uptake	0.990**	0.912*	0.980**	0.994**	0.996**	0.725	0.991**						
K Uptake	0.984**	0.919*	0.980**	0.993**	0.989**	0.686	0.989**	0.997**					
Chl	0.947*	0.877	0.938*	0.965**	0.965**	0.587	0.968**	0.982**	0.986**				
P_N	0.967**	0.892*	0.946*	0.967**	0.977**	0.709	0.952*	0.979**	0.967**	0.968**			
PWUE	0.973**	0.906*	0.955*	0.972**	0.978**	0.731	0.950*	0.980**	0.967**	0.961**	0.999**		
Oil Content	0.911*	0.785	0.866	0.897*	0.934*	0.723	0.900*	0.926*	0.900*	0.913*	0.976**	0.971**	
Oil Yield	0.979**	0.945*	0.971**	0.981**	0.973**	0.730	0.943*	0.977**	0.968**	0.953*	0.990**	0.995**	0.944*

* $(p = 0.05) = 0.878$
** $(p = 0.01) = 0.959$

ADW = Aboveground dry weight
Chl = Chlorophyll content
P_N = Photosynthetic rate
PWUE = Photosynthetic water use efficiency

Table 121. Correlation co-efficient (r) values among different parameters and with oil yield in *Mentha arvensis* L. at 105 DAP (Exp. 2)

Parameters	Plant Height	Leaf yield	Leaf number	Leaf area	Herb yield	ADW	N Uptake	P Uptake	K Uptake	Chl	P_N	PWUE	Oil Content
Leaf yield	0.917*												
Leaf number	0.992**	0.904*											
Leaf area	0.990**	0.915*	0.999**										
Herb yield	0.989**	0.934*	0.986**	0.987**									
ADW	0.950*	0.988**	0.950*	0.959**	0.956*								
N Uptake	0.913*	0.963**	0.924*	0.934*	0.955*	0.964**							
P Uptake	0.942*	0.989**	0.934*	0.943*	0.940*	0.997**	0.944*						
K Uptake	0.941*	0.958*	0.951*	0.959**	0.933*	0.989**	0.930*	0.986**					
Chl	0.976**	0.877	0.991**	0.990**	0.985**	0.923*	0.930*	0.897*	0.917*				
P_N	0.980**	0.940*	0.989**	0.993**	0.974**	0.980**	0.938*	0.970**	0.986**	0.969**			
PWUE	0.981**	0.954*	0.986**	0.990**	0.976**	0.987**	0.945*	0.979**	0.988**	0.963**	0.999**		
Oil Content	0.967**	0.976**	0.961**	0.967**	0.959**	0.995**	0.938*	0.995**	0.990**	0.927*	0.986**	0.992**	
Oil Yield	0.933*	0.998**	0.922*	0.932*	0.942*	0.995**	0.958*	0.996**	0.972**	0.892*	0.957*	0.969**	0.987**

* ($p = 0.05$) = 0.878
** ($p = 0.01$) = 0.959

ADW = Aboveground dry weight
Chl = Chlorophyll content
P_N = Photosynthetic rate
PWUE = Photosynthetic water use efficiency

Table 122. Correlation co-efficient (r) values among different parameters and with oil yield in *Mentha arvensis* L. at 120 DAP (Exp. 2)

Parameters	Plant Height	Leaf yield	Leaf number	Leaf area	Herb yield	ADW	N Uptake	P Uptake	K Uptake	Chl	P_N	PWUE	Oil Content
Leaf yield	0.901*												
Leaf number	0.880*	0.957*											
Leaf area	0.920*	0.963**	0.995**										
Herb yield	0.919*	0.944*	0.974**	0.977**									
ADW	0.932*	0.968**	0.971**	0.977**	0.996**								
N Uptake	0.951*	0.989**	0.957*	0.974**	0.948*	0.969**							
P Uptake	0.581	0.475	0.353	0.385	0.545	0.565	0.472						
K Uptake	0.948*	0.776	0.831	0.867	0.898*	0.882*	0.843	0.574					
Chl	0.868	0.954*	0.989**	0.980**	0.989**	0.985**	0.942*	0.454	0.830				
P_N	0.924*	0.938*	0.940*	0.947*	0.991**	0.992**	0.939*	0.650	0.894*	0.969**			
PWUE	0.922*	0.950*	0.969**	0.973**	0.999**	0.998**	0.952*	0.568	0.893*	0.987**	0.995**		
Oil Content	0.944*	0.987**	0.949**	0.962**	0.970**	0.988**	0.987**	0.585	0.852	0.957*	0.976**	0.976**	
Oil Yield	0.932*	0.996**	0.960**	0.970**	0.964**	0.984**	0.993**	0.528	0.827	0.961**	0.962**	0.969**	0.997**

* $(p = 0.05) = 0.878$
** $(p = 0.01) = 0.959$

ADW = Aboveground dry weight
Chl = Chlorophyll content
P_N = Photosynthetic rate
PWUE = Photosynthetic water use efficiency

Table 123. Correlation co-efficient (r) values among different parameters and with oil yield in *Mentha arvensis* L. at 135 DAP (Exp. 2)

Parameters	Plant Height	Leaf yield	Leaf number	Leaf area	Herb yield	ADW	N Uptake	P Uptake	K Uptake	Chl	P_N	PWUE	Oil Content
Leaf yield	0.945*												
Leaf number	0.918*	0.868											
Leaf area	0.908*	0.864	0.999**										
Herb yield	0.921*	0.921*	0.979**	0.981**									
ADW	0.960**	0.955*	0.969**	0.968**	0.992**								
N Uptake	0.915*	0.924*	0.981**	0.984**	0.996**	0.988**							
P Uptake	0.958*	0.933*	0.987**	0.986**	0.991**	0.995**	0.991**						
K Uptake	0.866	0.932*	0.938*	0.942*	0.971**	0.961**	0.984**	0.957*					
Chl	0.932*	0.965**	0.957*	0.958*	0.985**	0.989**	0.991**	0.985**	0.988**				
P_N	0.965**	0.977**	0.951*	0.949*	0.981**	0.996**	0.980**	0.988**	0.963**	0.992**			
PWUE	0.968**	0.986**	0.933*	0.930*	0.970**	0.991**	0.967**	0.978**	0.953*	0.986**	0.998**		
Oil Content	0.969**	0.926*	0.984**	0.981**	0.984**	0.992**	0.979**	0.997**	0.934*	0.972**	0.983**	0.974**	
Oil Yield	0.974**	0.959**	0.969**	0.966**	0.984**	0.998**	0.982**	0.996**	0.952*	0.987**	0.996**	0.992**	0.995**

* ($p = 0.05$) = 0.878
** ($p = 0.01$) = 0.959

ADW = Aboveground dry weight
Chl = Chlorophyll content
P_N = Photosynthetic rate
PWUE = Photosynthetic water use efficiency

Table 124. Correlation co-efficient (r) values among different parameters and with oil yield in *Mentha arvensis* L. at 150 DAP (Exp. 2)

Parameters	Plant Height	Leaf yield	Leaf number	Leaf area	Herb yield	ADW	N Uptake	P Uptake	K Uptake	Chl	P_N	PWUE	Oil Content
Leaf yield	0.992**												
Leaf number	0.987**	0.990**											
Leaf area	0.977**	0.979**	0.997**										
Herb yield	0.913*	0.937*	0.923*	0.927*									
ADW	0.950*	0.964**	0.953*	0.954*	0.994**								
N Uptake	0.933*	0.951*	0.955*	0.964**	0.989**	0.991**							
P Uptake	0.966**	0.983**	0.972**	0.970**	0.985**	0.996**	0.988**						
K Uptake	0.845	0.852	0.910*	0.937*	0.861	0.873	0.925*	0.878*					
Chl	0.966**	0.990**	0.977**	0.969**	0.968**	0.980**	0.972**	0.994**	0.863				
P_N	0.964**	0.980**	0.966**	0.963**	0.988**	0.997**	0.987**	0.999**	0.867	0.991**			
PWUE	0.979**	0.985**	0.975**	0.973**	0.977**	0.994**	0.982**	0.996**	0.872	0.985**	0.997**		
Oil Content	0.895*	0.922*	0.919*	0.928*	0.996**	0.986**	0.993**	0.977**	0.895*	0.957*	0.978**	0.965**	
Oil Yield	0.924*	0.947*	0.944*	0.950*	0.996**	0.994**	0.998**	0.989**	0.901*	0.975**	0.989**	0.980**	0.997**

* $(p = 0.05) = 0.878$
** $(p = 0.01) = 0.959$

ADW = Aboveground dry weight
Chl = Chlorophyll content
P_N = Photosynthetic rate
PWUE = Photosynthetic water use efficiency

Table 125. Correlation co-efficient (r) values among different parameters and with oil yield in *Mentha arvensis* L. at 90 DAP (Exp. 3)

Parameters	Plant Height	Leaf yield	Leaf number	Leaf area	Herb yield	ADW	N Uptake	P Uptake	K Uptake	Chl	P_N	PWUE	Oil Content
Leaf yield	0.398												
Leaf number	0.926	0.660											
Leaf area	0.801	0.853	0.955*										
Herb yield	0.224	0.976*	0.540	0.760									
ADW	0.206	0.973*	0.524	0.747	0.999**								
N Uptake	0.200	0.970*	0.521	0.744	0.999**	0.999**							
P Uptake	0.208	0.955*	0.542	0.752	0.994**	0.994**	0.995**						
K Uptake	0.186	0.958*	0.518	0.737	0.997**	0.997**	0.998**	0.999**					
Chl	0.159	0.963*	0.482	0.714	0.998**	0.999**	0.999**	0.992**	0.996**				
P_N	0.313	0.975*	0.627	0.819	0.992**	0.990**	0.990**	0.994**	0.991**	0.982*			
PWUE	0.424	0.979*	0.715	0.882	0.974*	0.969*	0.968*	0.974*	0.968*	0.956*	0.993**		
Oil Content	0.050	0.922	0.322	0.587	0.939	0.943	0.941	0.904	0.921	0.952*	0.890	0.853	
Oil Yield	0.349	0.998**	0.623	0.827	0.985*	0.983*	0.981*	0.967*	0.970*	0.976*	0.981*	0.978*	0.936

* $(p = 0.05) = 0.950$
** $(p = 0.01) = 0.990$

ADW = Aboveground dry weight
Chl = Chlorophyll content
P_N = Photosynthetic rate
PWUE = Photosynthetic water use efficiency

Table 126. Correlation co-efficient (r) values among different parameters and with oil yield in *Mentha arvensis* L. at 105 DAP (Exp. 3)

Parameters	Plant Height	Leaf yield	Leaf number	Leaf area	Herb yield	ADW	N Uptake	P Uptake	K Uptake	Chl	P_N	PWUE	Oil Content
Leaf yield	0.219												
Leaf number	0.890	0.635											
Leaf area	0.417	0.958*	0.785										
Herb yield	0.172	0.999**	0.597	0.946									
ADW	0.171	0.999**	0.597	0.946	0.999**								
N Uptake	0.255	0.999**	0.660	0.959*	0.996**	0.996**							
P Uptake	0.222	0.999**	0.636	0.956*	0.999**	0.999**	0.999**						
K Uptake	0.103	0.992**	0.542	0.933	0.997**	0.997**	0.986*	0.992**					
Chl	0.256	0.999**	0.664	0.965*	0.996**	0.996**	0.999**	0.999**	0.987*				
P_N	0.283	0.980*	0.690	0.990**	0.975*	0.975*	0.976*	0.979*	0.971*	0.982*			
PWUE	0.191	0.988*	0.618	0.970*	0.988*	0.988*	0.981*	0.986*	0.989*	0.986*	0.995**		
Oil Content	0.039	0.978*	0.474	0.877	0.985*	0.985*	0.973*	0.978*	0.987*	0.970*	0.925	0.953*	
Oil Yield	0.217	0.999**	0.633	0.959*	0.999**	0.999**	0.999**	0.999**	0.993**	0.999**	0.981*	0.989*	0.977*

* $(p = 0.05) = 0.950$
** $(p = 0.01) = 0.990$

ADW = Aboveground dry weight
Chl = Chlorophyll content
P_N = Photosynthetic rate
PWUE = Photosynthetic water use efficiency

Table 127. Correlation co-efficient (r) values among different parameters and with oil yield in *Mentha arvensis* L. at 120 DAP (Exp. 3)

Parameters	Plant Height	Leaf yield	Leaf number	Leaf area	Herb yield	ADW	N Uptake	P Uptake	K Uptake	Chl	P_N	PWUE	Oil Content
Leaf yield	0.462												
Leaf number	0.980*	0.597											
Leaf area	0.772	0.879	0.880										
Herb yield	0.534	0.995**	0.667	0.923									
ADW	0.596	0.971*	0.732	0.963*	0.990**								
N Uptake	0.351	0.992**	0.494	0.818	0.976*	0.941							
P Uptake	0.612	0.983*	0.733	0.947	0.995**	0.991**	0.954*						
K Uptake	0.618	0.981*	0.739	0.952*	0.995**	0.993**	0.950*	0.999**					
Chl	0.148	0.909	0.332	0.740	0.895	0.880	0.934	0.850	0.851				
P_N	0.136	0.941	0.291	0.681	0.906	0.853	0.975*	0.864	0.859	0.950*			
PWUE	0.140	0.941	0.291	0.677	0.905	0.849	0.976*	0.864	0.859	0.942	0.999**		
Oil Content	0.482	0.982*	0.633	0.921	0.990**	0.991**	0.967*	0.978*	0.980*	0.936	0.908	0.903	
Oil Yield	0.436	0.997**	0.581	0.881	0.994**	0.975*	0.992**	0.978*	0.977*	0.934	0.946	0.944	0.991**

* $(p = 0.05) = 0.950$
** $(p = 0.01) = 0.990$

ADW = Aboveground dry weight
Chl = Chlorophyll content
P_N = Photosynthetic rate
PWUE = Photosynthetic water use efficiency

Table 128. Correlation co-efficient (r) values among different parameters and with oil yield in *Mentha arvensis* L. at 135 DAP (Exp. 3)

Parameters	Plant Height	Leaf yield	Leaf number	Leaf area	Herb yield	ADW	N Uptake	P Uptake	K Uptake	Chl	P_N	PWUE	Oil Content
Leaf yield	0.229												
Leaf number	0.989*	0.329											
Leaf area	0.402	0.954*	0.515										
Herb yield	0.421	0.977*	0.518	0.985*									
ADW	0.420	0.977*	0.517	0.985*	0.999**								
N Uptake	0.181	0.998**	0.287	0.953*	0.968*	0.968*							
P Uptake	0.545	0.925	0.642	0.985*	0.984*	0.984*	0.914						
K Uptake	0.401	0.975*	0.505	0.994**	0.998**	0.998**	0.970*	0.985*					
Chl	0.308	0.987*	0.418	0.989*	0.990**	0.990**	0.987*	0.965*	0.995**				
P_N	0.289	0.957*	0.411	0.992**	0.968*	0.968*	0.964*	0.956*	0.982*	0.989*			
PWUE	0.311	0.965*	0.428	0.995**	0.977*	0.977*	0.970*	0.965*	0.989*	0.994**	0.999**		
Oil Content	0.592	0.882	0.691	0.975*	0.959*	0.959*	0.872	0.994**	0.965*	0.939	0.943	0.949	
Oil Yield	0.446	0.961*	0.549	0.995**	0.996**	0.996**	0.955*	0.993**	0.998**	0.989*	0.978*	0.985*	0.978*

* $(p = 0.05) = 0.950$
** $(p = 0.01) = 0.990$

ADW = Aboveground dry weight
Chl = Chlorophyll content
P_N = Photosynthetic rate
PWUE = Photosynthetic water use efficiency

Table 129. Correlation co-efficient (r) values among different parameters and with oil yield in *Mentha arvensis* L. at 150 DAP (Exp. 3)

Parameters	Plant Height	Leaf yield	Leaf number	Leaf area	Herb yield	ADW	N Uptake	P Uptake	K Uptake	Chl	P_N	PWUE	Oil Content
Leaf yield	0.127												
Leaf number	0.996**	0.187											
Leaf area	0.791	0.668	0.836										
Herb yield	0.345	0.969*	0.407	0.830									
ADW	0.347	0.968*	0.409	0.831	0.999**								
N Uptake	0.112	0.999**	0.175	0.667	0.969*	0.969*							
P Uptake	0.256	0.980*	0.305	0.716	0.963*	0.962*	0.969*						
K Uptake	0.608	0.828	0.667	0.966**	0.942	0.942	0.831	0.843					
Chl	0.587	0.813	0.649	0.959*	0.931	0.932	0.820	0.813	0.996**				
P_N	0.193	0.905	0.272	0.752	0.939	0.939	0.923	0.834	0.889	0.907			
PWUE	0.205	0.873	0.285	0.754	0.918	0.918	0.893	0.795	0.885	0.908	0.997**		
Oil Content	0.421	0.844	0.494	0.883	0.935	0.935	0.859	0.803	0.962*	0.978*	0.970*	0.974*	
Oil Yield	0.280	0.959*	0.350	0.805	0.990**	0.990**	0.967*	0.926	0.931	0.932	0.978*	0.964*	0.961*

* $(p = 0.05) = 0.950$
** $(p = 0.01) = 0.990$

ADW = Aboveground dry weight
Chl = Chlorophyll content
P_N = Photosynthetic rate
PWUE = Photosynthetic water use efficiency

Table 130. Correlation co-efficient (r) values among different parameters and with oil yield in *Mentha arvensis* L. at 90 DAP (Exp. 4)

Parameters	Plant Height	Leaf yield	Leaf number	Leaf area	Herb yield	ADW	N Uptake	P Uptake	K Uptake	Chl	P_N	PWUE	Oil Content
Leaf yield	0.990**												
Leaf number	0.964*	0.939											
Leaf area	0.950*	0.953*	0.979*										
Herb yield	0.996**	0.998**	0.944	0.944									
ADW	0.991**	0.999**	0.942	0.955*	0.998**								
N Uptake	0.999**	0.986*	0.962*	0.942	0.995**	0.987*							
P Uptake	0.991**	0.999**	0.946	0.958*	0.997**	0.999**	0.987*						
K Uptake	0.998**	0.997**	0.957*	0.957*	0.999**	0.998**	0.995**	0.998**					
Chl	0.934	0.924	0.987*	0.994**	0.919	0.928	0.927	0.932	0.936				
P_N	0.992**	0.983*	0.986*	0.980*	0.985*	0.985*	0.990**	0.986*	0.992**	0.971*			
PWUE	0.989*	0.985*	0.983*	0.985*	0.985*	0.987*	0.986*	0.988*	0.991**	0.974*	0.999**		
Oil Content	0.762	0.819	0.790	0.897	0.782	0.821	0.742	0.824	0.796	0.869	0.812	0.834	
Oil Yield	0.972*	0.992**	0.937	0.971*	0.982*	0.993**	0.965*	0.993**	0.985*	0.942	0.977*	0.984*	0.884

* $(p = 0.05) = 0.950$
** $(p = 0.01) = 0.990$

ADW = Aboveground dry weight
Chl = Chlorophyll content
P_N = Photosynthetic rate
PWUE = Photosynthetic water use efficiency

Table 131. Correlation co-efficient (r) values among different parameters and with oil yield in *Mentha arvensis* L. at 105 DAP (Exp. 4)

Parameters	Plant Height	Leaf yield	Leaf number	Leaf area	Herb yield	ADW	N Uptake	P Uptake	K Uptake	Chl	P_N	PWUE	Oil Content
Leaf yield	0.973*												
Leaf number	0.925	0.980*											
Leaf area	0.946	0.988*	0.998**										
Herb yield	0.962*	0.997**	0.992**	0.997**									
ADW	0.959*	0.997**	0.993**	0.997**	0.999**								
N Uptake	0.961*	0.996**	0.993**	0.998**	0.999**	0.999**							
P Uptake	0.959*	0.998**	0.989*	0.994**	0.999**	0.999**	0.998**						
K Uptake	0.954*	0.997**	0.992**	0.995**	0.999**	0.999**	0.998**	0.999**					
Chl	0.938	0.950*	0.972*	0.977*	0.965*	0.965*	0.971*	0.954*	0.956*				
P_N	0.944	0.978*	0.994**	0.997**	0.990**	0.990**	0.993**	0.984*	0.986*	0.991**			
PWUE	0.955*	0.993**	0.996**	0.999**	0.999**	0.999**	0.999**	0.997**	0.998**	0.973*	0.995**		
Oil Content	0.928	0.959*	0.986*	0.988*	0.975*	0.975*	0.980*	0.966*	0.969*	0.997**	0.997**	0.983*	
Oil Yield	0.964*	0.996**	0.992**	0.997**	0.999**	0.999**	0.999**	0.998**	0.998**	0.971*	0.993**	0.999**	0.980*

* $(p = 0.05) = 0.950$
** $(p = 0.01) = 0.990$

ADW = Aboveground dry weight
Chl = Chlorophyll content
P_N = Photosynthetic rate
PWUE = Photosynthetic water use efficiency

Table 132. Correlation co-efficient (r) values among different parameters and with oil yield in *Mentha arvensis* L. at 120 DAP (Exp. 4)

Parameters	Plant Height	Leaf yield	Leaf number	Leaf area	Herb yield	ADW	N Uptake	P Uptake	K Uptake	Chl	P_N	PWUE	Oil Content
Leaf yield	0.997**												
Leaf number	0.986*	0.976*											
Leaf area	0.996**	0.993**	0.995**										
Herb yield	0.999**	0.997**	0.984*	0.996**									
ADW	0.999**	0.997**	0.984*	0.996**	0.999**								
N Uptake	0.961*	0.962*	0.983*	0.980*	0.959*	0.959*							
P Uptake	0.980*	0.991**	0.937	0.967*	0.981*	0.981*	0.926						
K Uptake	0.999**	0.999**	0.976*	0.992**	0.999**	0.999**	0.954*	0.989*					
Chl	0.931	0.940	0.856	0.899	0.934	0.934	0.813	0.970*	0.946				
P_N	0.996**	0.999**	0.970*	0.989*	0.997**	0.997**	0.953*	0.993**	0.999**	0.950*			
PWUE	0.989*	0.997**	0.958*	0.981*	0.989*	0.989*	0.949	0.998**	0.995**	0.954*	0.998**		
Oil Content	0.995**	0.984*	0.995**	0.996**	0.994**	0.994**	0.963*	0.955*	0.988*	0.897	0.982*	0.969*	
Oil Yield	0.997**	0.989*	0.993**	0.997**	0.997**	0.997**	0.965*	0.963*	0.992**	0.907	0.987*	0.975*	0.999**

* $(p = 0.05) = 0.950$
** $(p = 0.01) = 0.990$

ADW = Aboveground dry weight
Chl = Chlorophyll content
P_N = Photosynthetic rate
PWUE = Photosynthetic water use efficiency

Table 133. Correlation co-efficient (r) values among different parameters and with oil yield in *Mentha arvensis* L. at 135 DAP (Exp. 4)

Parameters	Plant Height	Leaf yield	Leaf number	Leaf area	Herb yield	ADW	N Uptake	P Uptake	K Uptake	Chl	P_N	PWUE	Oil Content
Leaf yield	0.944												
Leaf number	0.968*	0.992**											
Leaf area	0.982*	0.972*	0.993**										
Herb yield	0.948	0.995**	0.997**	0.985*									
ADW	0.969*	0.965*	0.990**	0.998**	0.984*								
N Uptake	0.957*	0.999**	0.995**	0.978*	0.994**	0.970*							
P Uptake	0.923	0.925	0.960*	0.974*	0.958*	0.987*	0.927						
K Uptake	0.849	0.947	0.950*	0.932	0.967*	0.947	0.938	0.957*					
Chl	0.948	0.979*	0.993**	0.991**	0.994**	0.995**	0.979*	0.983*	0.973*				
P_N	0.928	0.975*	0.987*	0.981*	0.992**	0.988*	0.973*	0.982*	0.984*	0.998**			
PWUE	0.896	0.975*	0.977*	0.961*	0.989*	0.968*	0.970*	0.963*	0.994**	0.989*	0.995**		
Oil Content	0.888	0.983*	0.975*	0.950*	0.988*	0.954*	0.976*	0.937	0.987*	0.979*	0.985*	0.996**	
Oil Yield	0.895	0.988*	0.978*	0.951*	0.990**	0.953*	0.982*	0.931	0.980*	0.978*	0.983*	0.993**	0.999**

* $(p = 0.05) = 0.950$
** $(p = 0.01) = 0.990$

ADW = Aboveground dry weight
Chl = Chlorophyll content
P_N = Photosynthetic rate
PWUE = Photosynthetic water use efficiency

Table 134. Correlation co-efficient (r) values among different parameters and with oil yield in *Mentha arvensis* L. at 150 DAP (Exp. 4)

Parameters	Plant Height	Leaf yield	Leaf number	Leaf area	Herb yield	ADW	N Uptake	P Uptake	K Uptake	Chl	P_N	PWUE	Oil Content
Leaf yield	0.978*												
Leaf number	0.978*	0.942											
Leaf area	0.994**	0.976*	0.992**										
Herb yield	0.960*	0.944	0.992**	0.984*									
ADW	0.979*	0.989*	0.974*	0.990**	0.982*								
N Uptake	0.991**	0.995**	0.952*	0.983*	0.942	0.984*							
P Uptake	0.943	0.968*	0.957*	0.968*	0.981*	0.990**	0.951*						
K Uptake	0.956*	0.985*	0.951*	0.972*	0.971*	0.995**	0.970*	0.996**					
Chl	0.935	0.976*	0.933	0.955*	0.960*	0.987*	0.955*	0.996**	0.998**				
P_N	0.942	0.942	0.978*	0.972*	0.996**	0.981*	0.932	0.990**	0.978*	0.973*			
PWUE	0.910	0.922	0.955*	0.947	0.984*	0.966*	0.904	0.988*	0.972*	0.973*	0.996**		
Oil Content	0.907	0.931	0.945	0.943	0.978*	0.969*	0.909	0.993**	0.979*	0.982*	0.992**	0.998**	
Oil Yield	0.963*	0.984*	0.963*	0.979*	0.979*	0.997**	0.971*	0.997**	0.999**	0.995**	0.984*	0.977*	0.981*

* $(p = 0.05) = 0.950$
** $(p = 0.01) = 0.990$

ADW = Aboveground dry weight
Chl = Chlorophyll content
P_N = Photosynthetic rate
PWUE = Photosynthetic water use efficiency

Table 135. Correlation co-efficient (r) values among different parameters and with oil yield in *Mentha arvensis* L. at 90 DAP (Exp. 5)

Parameters	Plant Height	Leaf yield	Leaf number	Leaf area	Herb yield	ADW	N Uptake	P Uptake	K Uptake	Chl	P_N	PWUE	Oil Content
Leaf yield	0.551*												
Leaf number	0.656**	0.855**											
Leaf area	0.356	0.810**	0.903**										
Herb yield	0.574**	0.966**	0.907**	0.862**									
ADW	0.643**	0.954**	0.907**	0.858**	0.962**								
N Uptake	0.520*	0.697**	0.865**	0.851**	0.770**	0.825**							
P Uptake	0.502*	0.832**	0.857**	0.848**	0.819**	0.890**	0.829**						
K Uptake	0.530*	0.822**	0.886**	0.878**	0.806**	0.882**	0.817**	0.956**					
Chl	0.532*	0.946**	0.904**	0.886**	0.946**	0.924**	0.710**	0.850**	0.859**				
P_N	0.529*	0.846**	0.821**	0.805**	0.884**	0.920**	0.854**	0.803**	0.785**	0.805**			
PWUE	0.513*	0.844**	0.813**	0.798**	0.879**	0.913**	0.840**	0.802**	0.782**	0.803**	0.998**		
Oil Content	0.676**	0.413	0.619**	0.406	0.520*	0.501*	0.669**	0.307	0.310	0.363	0.545*	0.523*	
Oil Yield	0.646**	0.958**	0.906**	0.803**	0.962**	0.945**	0.788**	0.788**	0.788**	0.900**	0.881**	0.875**	0.645**

* $(p = 0.05) = 0.444$
** $(p = 0.01) = 0.561$

ADW = Aboveground dry weight
Chl = Chlorophyll content
P_N = Photosynthetic rate
PWUE = Photosynthetic water use efficiency

Table 136. Correlation co-efficient (r) values among different parameters and with oil yield in *Mentha arvensis* L. at 105 DAP (Exp. 5)

Parameters	Plant Height	Leaf yield	Leaf number	Leaf area	Herb yield	ADW	N Uptake	P Uptake	K Uptake	Chl	P_N	PWUE	Oil Content
Leaf yield	0.597**												
Leaf number	0.755**	0.762**											
Leaf area	0.669**	0.762**	0.978**										
Herb yield	0.693**	0.926**	0.910**	0.899**									
ADW	0.712**	0.924**	0.908**	0.898**	0.994**								
N Uptake	0.554*	0.923**	0.736**	0.749**	0.883**	0.901**							
P Uptake	0.672**	0.935**	0.879**	0.874**	0.962**	0.962**	0.896**						
K Uptake	0.701**	0.881**	0.870**	0.865**	0.948**	0.959**	0.871**	0.926**					
Chl	0.586**	0.954**	0.753**	0.759**	0.906**	0.921**	0.931**	0.920**	0.876**				
P_N	0.711**	0.794**	0.841**	0.813**	0.871**	0.881**	0.789**	0.868**	0.894**	0.846**			
PWUE	0.682**	0.903**	0.832**	0.832**	0.953**	0.957**	0.879**	0.922**	0.903**	0.904**	0.891**		
Oil Content	0.660**	0.908**	0.835**	0.839**	0.927**	0.938**	0.896**	0.914**	0.897**	0.913**	0.913**	0.959**	
Oil Yield	0.641**	0.982**	0.807**	0.811**	0.942**	0.946**	0.928**	0.943**	0.900**	0.959**	0.859**	0.946**	0.968**

* $(p = 0.05) = 0.444$
** $(p = 0.01) = 0.561$

ADW = Aboveground dry weight
Chl = Chlorophyll content
P_N = Photosynthetic rate
PWUE = Photosynthetic water use efficiency

Table 137. Correlation co-efficient (r) values among different parameters and with oil yield in *Mentha arvensis* L. at 120 DAP (Exp. 5)

Parameters	Plant Height	Leaf yield	Leaf number	Leaf area	Herb yield	ADW	N Uptake	P Uptake	K Uptake	Chl	P_N	PWUE	Oil Content
Leaf yield	0.355												
Leaf number	0.591**	0.730**											
Leaf area	0.523*	0.846**	0.953**										
Herb yield	0.380	0.968**	0.736**	0.853**									
ADW	0.379	0.966**	0.732**	0.847**	0.999**								
N Uptake	0.316	0.962**	0.690**	0.805**	0.948**	0.945**							
P Uptake	0.330	0.868**	0.627**	0.745**	0.934**	0.935**	0.870**						
K Uptake	0.172	0.935**	0.627**	0.762**	0.899**	0.896**	0.921**	0.784**					
Chl	0.342	0.973**	0.756**	0.852**	0.917**	0.913**	0.948**	0.814**	0.908**				
P_N	0.380	0.919**	0.734**	0.830**	0.972**	0.973**	0.907**	0.883**	0.855**	0.847**			
PWUE	0.393	0.905**	0.697**	0.807**	0.966**	0.967**	0.901**	0.884**	0.846**	0.825**	0.990**		
Oil Content	0.626**	0.740**	0.851**	0.860**	0.761**	0.759**	0.661**	0.703**	0.632**	0.761**	0.732**	0.706**	
Oil Yield	0.493*	0.952**	0.844**	0.919**	0.943**	0.940**	0.898**	0.852**	0.866**	0.947**	0.906**	0.884**	0.908**

* $(p = 0.05) = 0.444$
** $(p = 0.01) = 0.561$

ADW = Aboveground dry weight
Chl = Chlorophyll content
P_N = Photosynthetic rate
PWUE = Photosynthetic water use efficiency

Table 138. Correlation co-efficient (r) values among different parameters and with oil yield in *Mentha arvensis* L. at 135 DAP (Exp. 5)

Parameters	Plant Height	Leaf yield	Leaf number	Leaf area	Herb yield	ADW	N Uptake	P Uptake	K Uptake	Chl	P_N	PWUE	Oil Content
Leaf yield	0.490*												
Leaf number	0.736**	0.797**											
Leaf area	0.678**	0.892**	0.962**										
Herb yield	0.636**	0.961**	0.871**	0.935**									
ADW	0.668**	0.955**	0.887**	0.940**	0.997**								
N Uptake	0.489*	0.956**	0.747**	0.829**	0.951**	0.948**							
P Uptake	0.522*	0.901**	0.743**	0.832**	0.889**	0.886**	0.867**						
K Uptake	0.617**	0.947**	0.851**	0.914**	0.938**	0.941**	0.892**	0.899**					
Chl	0.620**	0.955**	0.846**	0.911**	0.974**	0.971**	0.931**	0.876**	0.925**				
P_N	0.620**	0.953**	0.888**	0.935**	0.985**	0.987**	0.953**	0.874**	0.927**	0.957**			
PWUE	0.657**	0.945**	0.890**	0.937**	0.987**	0.990**	0.942**	0.869**	0.934**	0.963**	0.994**		
Oil Content	0.684**	0.587**	0.759**	0.775**	0.738**	0.741**	0.558*	0.668**	0.648**	0.669**	0.697**	0.738**	
Oil Yield	0.686**	0.897**	0.887**	0.936**	0.962**	0.961**	0.860**	0.886**	0.907**	0.924**	0.935**	0.951**	0.870**

* $(p = 0.05) = 0.444$
** $(p = 0.01) = 0.561$

ADW = Aboveground dry weight
Chl = Chlorophyll content
P_N = Photosynthetic rate
PWUE = Photosynthetic water use efficiency

Table 139. Correlation co-efficient (r) values among different parameters and with oil yield in *Mentha arvensis* L. at 150 DAP (Exp. 5)

Parameters	Plant Height	Leaf yield	Leaf number	Leaf area	Herb yield	ADW	N Uptake	P Uptake	K Uptake	Chl	P_N	PWUE	Oil Content
Leaf yield	0.497*												
Leaf number	0.777**	0.783**											
Leaf area	0.662**	0.884**	0.949**										
Herb yield	0.652**	0.964**	0.861**	0.910**									
ADW	0.674**	0.963**	0.875**	0.921**	0.995**								
N Uptake	0.447*	0.937**	0.667**	0.773**	0.884**	0.894**							
P Uptake	0.461*	0.842**	0.658**	0.722**	0.846**	0.841**	0.808**						
K Uptake	0.655**	0.870**	0.802**	0.850**	0.904**	0.903**	0.837**	0.722**					
Chl	0.619**	0.945**	0.828**	0.877**	0.958**	0.958**	0.883**	0.882**	0.836**				
P_N	0.614**	0.940**	0.878**	0.921**	0.972**	0.973**	0.878**	0.788**	0.916**	0.927**			
PWUE	0.645**	0.937**	0.895**	0.928**	0.977**	0.979**	0.873**	0.797**	0.918**	0.937**	0.997**		
Oil Content	0.759**	0.649**	0.870**	0.835**	0.777**	0.776**	0.520*	0.645**	0.762**	0.704**	0.755**	0.785**	
Oil Yield	0.659**	0.900**	0.918**	0.955**	0.948**	0.944**	0.786**	0.793**	0.902**	0.889**	0.930**	0.942**	0.900**

* $(p = 0.05) = 0.444$
** $(p = 0.01) = 0.561$

ADW = Aboveground dry weight
Chl = Chlorophyll content
P_N = Photosynthetic rate
PWUE = Photosynthetic water use efficiency

Table 140. Correlation co-efficient (r) values among different parameters and with oil yield in *Mentha arvensis* L. at 90 DAP (Exp. 6)

Parameters	Plant Height	Leaf yield	Leaf number	Leaf area	Herb yield	ADW	N Uptake	P Uptake	K Uptake	Chl	P_N	PWUE	Oil Content
Leaf yield	0.759**												
Leaf number	0.769**	0.909**											
Leaf area	0.813**	0.911**	0.929**										
Herb yield	0.743**	0.965**	0.924**	0.914**									
ADW	0.745**	0.964**	0.925**	0.912**	0.999**								
N Uptake	0.733**	0.926**	0.915**	0.912**	0.982**	0.984**							
P Uptake	0.649**	0.867**	0.784**	0.774**	0.895**	0.900**	0.878**						
K Uptake	0.701**	0.886**	0.876**	0.858**	0.969**	0.970**	0.976**	0.863**					
Chl	0.694**	0.913**	0.864**	0.864**	0.944**	0.941**	0.936**	0.877**	0.909**				
P_N	0.648**	0.890**	0.860**	0.865**	0.921**	0.923**	0.908**	0.881**	0.891**	0.883**			
PWUE	0.670**	0.915**	0.871**	0.866**	0.954**	0.957**	0.952**	0.905**	0.934**	0.945**	0.934**		
Oil Content	0.714**	0.678**	0.687**	0.600**	0.663**	0.667**	0.614**	0.699**	0.654**	0.560**	0.642**	0.564**	
Oil Yield	0.796**	0.951**	0.891**	0.854**	0.919**	0.920**	0.872**	0.876**	0.862**	0.856**	0.870**	0.860**	0.866**

* $(p = 0.05) = 0.444$
** $(p = 0.01) = 0.561$

ADW = Aboveground dry weight
Chl = Chlorophyll content
P_N = Photosynthetic rate
PWUE = Photosynthetic water use efficiency

Table 141. Correlation co-efficient (r) values among different parameters and with oil yield in *Mentha arvensis* L. at 105 DAP (Exp. 6)

Parameters	Plant Height	Leaf yield	Leaf number	Leaf area	Herb yield	ADW	N Uptake	P Uptake	K Uptake	Chl	P_N	PWUE	Oil Content
Leaf yield	0.674**												
Leaf number	0.831**	0.735**											
Leaf area	0.763**	0.704**	0.967**										
Herb yield	0.756**	0.930**	0.882**	0.888**									
ADW	0.756**	0.930**	0.882**	0.887**	0.999**								
N Uptake	0.676**	0.936**	0.816**	0.820**	0.974**	0.974**							
P Uptake	0.708**	0.904**	0.731**	0.712**	0.915**	0.915**	0.897**						
K Uptake	0.703**	0.948**	0.844**	0.845**	0.979**	0.979**	0.963**	0.880**					
Chl	0.716**	0.992**	0.768**	0.741**	0.943**	0.943**	0.941**	0.923**	0.943**				
P_N	0.737**	0.842**	0.917**	0.918**	0.920**	0.920**	0.886**	0.819**	0.898**	0.871**			
PWUE	0.720**	0.806**	0.897**	0.884**	0.871**	0.871**	0.830**	0.786**	0.842**	0.843**	0.975**		
Oil Content	0.600**	0.837**	0.745**	0.690**	0.807**	0.807**	0.776**	0.825**	0.793**	0.850**	0.781**	0.780**	
Oil Yield	0.655**	0.982**	0.743**	0.704**	0.915**	0.915**	0.912**	0.906**	0.932**	0.975**	0.829**	0.795**	0.918**

* $(p = 0.05) = 0.444$
** $(p = 0.01) = 0.561$

ADW = Aboveground dry weight
Chl = Chlorophyll content
P_N = Photosynthetic rate
PWUE = Photosynthetic water use efficiency

Table 142. Correlation co-efficient (r) values among different parameters and with oil yield in *Mentha arvensis* L. at 120 DAP (Exp. 6)

Parameters	Plant Height	Leaf yield	Leaf number	Leaf area	Herb yield	ADW	N Uptake	P Uptake	K Uptake	Chl	P_N	PWUE	Oil Content
Leaf yield	0.481*												
Leaf number	0.668**	0.703**											
Leaf area	0.669**	0.695**	0.789**										
Herb yield	0.498*	0.952**	0.722**	0.742**									
ADW	0.497*	0.951**	0.720**	0.746**	0.999**								
N Uptake	0.527*	0.922**	0.686**	0.702**	0.963**	0.962**							
P Uptake	0.447*	0.845**	0.673**	0.598**	0.896**	0.898**	0.819**						
K Uptake	0.412	0.870**	0.655**	0.757**	0.944**	0.944**	0.929**	0.789**					
Chl	0.522*	0.952**	0.688**	0.732**	0.925**	0.925**	0.849**	0.860**	0.846**				
P_N	0.565**	0.902**	0.641**	0.750**	0.960**	0.961**	0.911**	0.889**	0.924**	0.906**			
PWUE	0.573**	0.904**	0.640**	0.752**	0.957**	0.959**	0.907**	0.887**	0.918**	0.908**	0.999**		
Oil Content	0.375	0.628**	0.805**	0.680**	0.590**	0.585**	0.521*	0.483*	0.558*	0.603**	0.477*	0.479*	
Oil Yield	0.464*	0.931**	0.826**	0.756**	0.885**	0.882**	0.829**	0.773**	0.820**	0.892**	0.795**	0.796**	0.866**

* $(p = 0.05) = 0.444$
** $(p = 0.01) = 0.561$

ADW = Aboveground dry weight
Chl = Chlorophyll content
P_N = Photosynthetic rate
PWUE = Photosynthetic water use efficiency

Table 143. Correlation co-efficient (r) values among different parameters and with oil yield in *Mentha arvensis* L. at 135 DAP (Exp. 6)

Parameters	Plant Height	Leaf yield	Leaf number	Leaf area	Herb yield	ADW	N Uptake	P Uptake	K Uptake	Chl	P_N	PWUE	Oil Content
Leaf yield	0.446*												
Leaf number	0.734**	0.680**											
Leaf area	0.663**	0.596**	0.852**										
Herb yield	0.551*	0.970**	0.768**	0.711**									
ADW	0.489*	0.943**	0.787**	0.713**	0.969**								
N Uptake	0.451*	0.896**	0.759**	0.710**	0.953**	0.940**							
P Uptake	0.382	0.929**	0.618**	0.511*	0.927**	0.935**	0.892**						
K Uptake	0.480*	0.954**	0.764**	0.634**	0.937**	0.969**	0.889**	0.900**					
Chl	0.429	0.929**	0.608**	0.619**	0.950**	0.903**	0.900**	0.901**	0.851**				
P_N	0.482*	0.959**	0.703**	0.655**	0.968**	0.956**	0.912**	0.946**	0.918**	0.922**			
PWUE	0.508*	0.927**	0.739**	0.659**	0.948**	0.933**	0.892**	0.903**	0.894**	0.889**	0.984**		
Oil Content	0.689**	0.560*	0.836**	0.957**	0.671**	0.670**	0.659**	0.466*	0.598**	0.615**	0.597**	0.608**	
Oil Yield	0.650**	0.869**	0.871**	0.896**	0.919**	0.904**	0.874**	0.772**	0.868**	0.859**	0.870**	0.862**	0.896**

* $(p = 0.05) = 0.444$
** $(p = 0.01) = 0.561$

ADW = Aboveground dry weight
Chl = Chlorophyll content
P_N = Photosynthetic rate
PWUE = Photosynthetic water use efficiency

Table 144. Correlation co-efficient (r) values among different parameters and with oil yield in *Mentha arvensis* L. at 150 DAP (Exp. 6)

Parameters	Plant Height	Leaf yield	Leaf number	Leaf area	Herb yield	ADW	N Uptake	P Uptake	K Uptake	Chl	P_N	PWUE	Oil Content
Leaf yield	0.355												
Leaf number	0.755**	0.651**											
Leaf area	0.693**	0.563**	0.863**										
Herb yield	0.493*	0.960**	0.756**	0.694**									
ADW	0.483*	0.963**	0.758**	0.691**	0.999**								
N Uptake	0.321	0.845**	0.510*	0.586**	0.847**	0.840**							
P Uptake	0.373	0.961**	0.616**	0.488*	0.950**	0.951**	0.825**						
K Uptake	0.525*	0.912**	0.796**	0.749**	0.934**	0.939**	0.774**	0.890**					
Chl	0.353	0.940**	0.634**	0.591**	0.956**	0.956**	0.867**	0.926**	0.871**				
P_N	0.449*	0.936**	0.714**	0.694**	0.963**	0.960**	0.835**	0.911**	0.924**	0.928**			
PWUE	0.403	0.908**	0.701**	0.682**	0.927**	0.924**	0.821**	0.884**	0.895**	0.895**	0.988**		
Oil Content	0.712**	0.514*	0.825**	0.930**	0.642**	0.639**	0.511*	0.416	0.686**	0.577**	0.592**	0.542*	
Oil Yield	0.644**	0.825**	0.873**	0.899**	0.887**	0.886**	0.752**	0.739**	0.902**	0.828**	0.853**	0.813**	0.905**

* $(p = 0.05) = 0.444$
** $(p = 0.01) = 0.561$

ADW = Aboveground dry weight
Chl = Chlorophyll content
P_N = Photosynthetic rate
PWUE = Photosynthetic water use efficiency

SUMMARY

Chapter 6

SUMMARY

The present thesis entitled "Studies on physiomorphological response of *Mentha arvensis* L. to nitrogen, phosphorus, gibberellic acid and kinetin application" comprises six chapters.

In Chapter 1 (Introduction), the importance of the problem and the lacunae in earlier attempts to solve it together with justification for selecting it have been put forward.

Chapter 2 (Review of Literature) comprises compilation of relevant available literature pertaining to individual as well as interaction effect of nitrogen (N) and phosphorus (P) with gibberellic acid (GA_3) and kinetin (Kn) on the growth and development of the crop.

Chapter 3 (Materials and Methods) deals with the details of the material used and the technique employed for six pot experiments conducted alongwith relevant information on meteorological and edaphic data.

Chapter 4 (Results) deals with detailed data regarding the response of the crop to the treatments calculated at $p<0.05$.

Chapter 5 (Discussion) includes a critical assessment of the significant results in the context of earlier findings and the more salient points are summarised below.

Experiment 1 (20^{th} February to 15^{th} July, 2000) was conducted according to simple randomised design to study the effect of application of nitrogen on *Mentha arvensis* L. with regard to (i) growth (plant height, root length, leaf area, leaf area ratio, specific leaf area, leaf dry weight, specific leaf weight, stem dry weight, aboveground plant dry weight, underground plant fresh and dry weight), (ii) physiology on the basis of chlorophyll content, chlorophyll harvest, photosynthetic rate, stomatal conductance, photosynthetic water use efficiency, nutrient (NPK) content and nutrient (NPK) uptake, (iii) yield characteristics, such as leaf number, branch number, leaf yield, stem yield, herb yield, oil content and oil yield. Nitrogen was applied at 0, 30, 60, 90 and 120kg N/ha at 70 days after planting (DAP), and data on different characteristics were recorded at 90, 105, 120, 135 and 150 DAP.

Application of 90kg N/ha proved best among the doses of nitrogen tested for almost all growth, physiological and yield characteristics. The maximum per cent increase in almost all growth, physiological and yield characteristics studied was observed at 105 DAP. At this stage, an increase of 79, 23 and 46 per cent in leaf area, specific leaf area and herb yield respectively was noted because of application of 90kg N/ha.

Experiment 2 (20th February to 15th July, 2000) was conducted according to simple randomized design. The aim of this experiment was to find out a suitable dose of phosphorus for optimum response of *Mentha arvensis* L. The applied doses of phosphorus at 70 DAP were 0, 10, 20, 30 and 40kg P/ha. The parameters and timings of sampling were those mentioned in Experiment 1. The dose of 30kg P/ha gave best in enhancing the characteristics studied in other doses. The maximum per cent increase in almost all growth, physiological and yield characteristics was observed at 105 DAP. At this stage, an increase of 92, 52 and 66 per cent in leaf area, specific leaf area and herb yield respectively caused by 30kg P/ha.

Experiment 3 (20th February to 15th July, 2000) was conducted according to simple randomized design to determine the effects of foliar spray of gibberellic acid (GA_3) at 70 DAP on *Mentha arvensis* L. The GA_3 treatments were 10^{-4}M, 10^{-3}M, 10^{-2}M and water spray as control (W_0). The parameters and stages of sampling were the same as in Experiment 1 and 2. Among GA_3 treatments, 10^{-4}M proved best for most growth, physiological and yield characteristics. Maximum per cent increase for most parameters recorded at 105 DAP. An increase in leaf area and herb yield generated by 10^{-4}M GA_3 was 26 and 50 per cent respectively.

Experiment 4 (20th February to 15th July, 2000) was conducted according to simple randomized design to assess the effect of foliar spray of kinetin treatments at a concentration of 10^{-6}M, 10^{-5}M, 10^{-4}M and water spray as control (W_0). The spray of kinetin (Kn) was done at 70 DAP. The growth, physiological and yield characteristics and stages of sampling were the same as in pervious experiments.

Among Kn treatments, 10^{-5}M proved best for all the characteristics studied. Like in other experiments, maximum per cent increase for most parameters was noted at 105 DAP. At this stage, an increase of 59, 24 and 66 per cent in leaf area, specific leaf area and herb yield respectively resulted from application of 10^{-5}M Kn.

Experiment 5 (20th February to 15th July, 2001) was conducted to study the interaction effect of soil-applied nitrogen and leaf-applied gibberellic acid (GA_3) or kinetin (Kn). The applied rates of nitrogen (selected on the basis of Experiment 1) were 0, 60, 90 and 120kg N/ha. Gibberellic acid treatments (selected on the basis of Experiment 3) were 10^{-5}M and 10^{-4}M and kinetin treatments (selected on the basis of Experiment 4) were 10^{-6}M and 10^{-5}M. Water spray (W_0) was taken as control. The soil and foliar treatments were given at 70 DAP. The characteristics and stages of sampling were the same as those studied in earlier experiments. Application of 90kg N/ha and $10^{-5}GA_3$ alone proved best for almost all characteristics studied. Interaction of 90kg N/ha × 10^{-5}M GA_3 proved superior for above ground plant characteristics. However, for underground plant characteristics the interaction N_{90} × 10^{-6}M Kn proved best. In this experiment also, maximum per cent increase for most parameters was recorded at 105 DAP. An increase in leaf area and herb yield generated by 90kg N/ha × 10^{-5}M GA_3 was 221 and 117 per cent respectively at 105 DAP.

Experiment 6 (20th February to 15th July, 2001) was conducted to assess the interaction effect of soil-applied phosphorus and foliar spray of gibberellic acid (GA_3) and kinetin (Kn) on performance of *Mentha arvensis* L. The applied rates of phosphorus (selected on the basis of Experiment 2) were 0, 20, 30 and 40kg P/ha. Gibberelic acid treatments (selected on the basis of Experiment 3) were 10^{-5}M and 10^{-4}M and kinetin treatments (selected on the basis of Experiment 4) were 10^{-6}M and 10^{-5}M. Water spray (W_0) was taken as control. The soil and foliar treatments were applied at 70 DAP. The characteristics and sampling timings were the same as in earlier experiments. Application of 30kg P/ha and 10^{-5}M GA_3 alone gave best results. Interaction 30kg P/ha × 10^{-5}M GA_3 prove best for above ground plant characteristics, while P_{30} × 10^{-6}M Kn for underground plant characteristics. Like other experiments, maximum per cent increase for most parameters was noted at 105 DAP. Application of 40kg P/ha × 10^{-5}M GA_3 gave 185 and 100% higher leaf area and herb yield respectively at 105 DAP.

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APPENDIX

APPENDIX

Preparation of Reagents

The reagents for N, P and K determination were prepared according to the following methodology

Reagents for N, P and K determination

1. Nessler's reagent

3.5 mg of potassium iodide were dissolved in 100 ml of distilled water in which 4 per cent mercuric chloride solution was added with stirring until a slide red precipitate remained. Therefore, 120 g of sodium hydroxide with 250 ml of distilled water added. The volume was made upto one litre with distilled water. The mixture was decanted and kept in an amber-coloured bottle.

2. Molybdic acid reagent (2.5%)

1.25 mg of ammonium molybdate were dissolved in 175 ml of distilled water in which 75 ml of 10 N sulphuric acid were added.

3. Aminonapthol sulphuric acid

0.5 mg of 1-amino-2-napthol-4-sulphonic acid were dissolved in 195 ml of 15 per cent sodium bisulphate solution to which 5 ml of 20 per cent of sodium sulphate solution was added.